Lewis River LWD Assessment

Draft – Oct 1, 2007

Prepared for:
PacifiCorp
825 Multnomah
Suite 1500
Portland, OR 97232

Prepared by:

Inter-Fluve, Inc., Hood River, OR
Fox Environmental Services, LLC, Roslyn, WA
Cramer Fish Sciences, Inc., Gresham, OR

Primary Authors:
Gardner Johnston, Inter-Fluve Inc.
Martin Fox, Fox Environmental Services, LLC
Jody Lando, Cramer Fish Sciences

Table of Contents

Introduction

Overview

The objective of this study is to "*identify and assess the potential benefits of LWD projects below Merwin Dam and provide conceptual approaches for supplementing available supply and promoting retention of LWD in the river below Merwin Dam to promote aquatic habitat complexity*" (Section 7.1.2 of Settlement Agreement). In support of this objective, several analyses have been conducted. These include the following:

1) Reference conditions– this assessment characterizes the historical basin wood supply and instream wood conditions (below Merwin Dam) that would have been expected to occur in the Lewis basin prior to European settlement. This evaluation is based on the concept that understanding historical conditions provides a reference that is useful for determining restoration objectives and approaches.
2) Existing and projected conditions– this assessment characterizes the existing basin wood supply that would be available to the river below Merwin if it were transported around the hydropower system. This evaluation also characterizes the ability of the lower river to retain wood under existing conditions. This evaluation is useful for determining the wood supply that may be available for re-introduction into the lower river. It also helps to determine whether re-introduced wood would accumulate naturally in the river or if artificial anchoring measures are necessary.
3) LWD project opportunities – this evaluation identifies and describes potential opportunities to re-introduce LWD to the lower river below Merwin Dam. Potential techniques and locations are provided. Necessary anchoring techniques are discussed. Photos and maps are provided that accompany project descriptions. Costs, risks, and logistical constraints are provided for each project opportunity.
4) Fish benefits from wood re-introduction – this analysis evaluates the potential benefits accrued to fish from wood re-introduction measures. Quantitative and qualitative assessments are provided of the effect of wood re-introduction on species life-stages that occur in the lower Lewis. Potential change in fish benefits from historical conditions to potential restored conditions is discussed.

Background

Wood derived from fallen trees is ubiquitous in many undisturbed stream and river channels, not only in the Pacific Northwest but also in forested landscapes throughout the world. These pieces of large woody debris (LWD) have many roles in these systems, including trapping sediment, diverting low and high flows, and providing cover and shading for aquatic organisms. Although the influence of any particular piece of LWD is difficult to predict and likely to change over time, both functionally and spatially, the collective effects of LWD can be substantial and very persistent. LWD is a key ecosystem component for stream organisms, particularly fish and notably anadromous salmon. It has been part of virtually all temperate Pacific Northwest freshwater systems for many thousands of years, and its role is significant at every life stage of most salmonids.

The recent history of LWD in rivers and streams has been much more varied. The removal of wood from streams (also known as "stream cleaning") was once common practice in the Pacific Northwest (Bisson et al. 1987), particularly between the 1950s and 1970s. To "improve" upstream fish passage, state and local programs were successful at eradicating wood from many streams (Reeves et al. 1991); repercussions to fish habitat still exist as a result of these practices (Bisson et al. 1987). Instream wood was recognized only for its ability to block culverts or to lodge under bridges. Its presence in the active flow complicated any estimates of roughness or channel capacity, and the scour imparted by associated flow deflections was seen as a threat to bank stability and to orderly channel geometry.

Several factors in recent decades have driven significant reevaluation and revision of the perceptions of LWD. Resource managers recognize adverse changes in stream-channel morphology and stability following the removal of LWD that has historically accompanied land-use changes. Furthermore, there is increasing public interest in restored biological productivity, particularly fish, which in turn requires recovery of habitat-forming processes and elements.

Habitat-restoration efforts have increased dramatically since the early 1980s. In the Pacific Northwest, these efforts accelerated once the importance of woody debris in forming salmonid habitat became widely accepted (Bilby and Likens 1980; Bisson et al. 1987). The paucity of instream wood due to land-use practices and past stream cleaning has resulted in the common use of wood-placement projects for enhancing salmonid habitat (Kauffman et al. 1997). The use of LWD has also been incorporated into bank protection, wherein the practice of substituting logs for rock as bank armoring is intended to prevent lateral migration or avulsion (Babakaiff et al. 1997). In some cases, this practice is intended to slow bank erosion rates accelerated by the denudation of riparian vegetation until this vegetation can return. In most cases, however, these measures have been employed to protect a road, bridge, building, property, or other anthropogenic feature located in the floodplain (Nichols and Sprague 2003), largely independent of its ecological effects.

Restoration of river systems is best done by restoring the natural ecological processes of the watershed, one of which is the component of restoring wood loads to stream channels. Unfortunately, in disturbed watersheds, this process may take longer than socially and biologically acceptable, particularly if the recovery of critical salmon populations is a priority. In this case, 'jump-starting' the restorative processes for fish habitat and other riverine ecological functions may be enhanced by the artificial introduction of wood.

It is worth noting that even with widespread usage in both scientific and agency literature, "Large Woody Debris" has no universal definition. Although the type of material—logs, branches, rootwads—is generally accepted by all, there are no absolute size criteria for what is sufficiently "large." Minimum diameters of between 10 and 25 cm (4-10 in) are common criteria in the published literature (Bilby and Ward 1989; Beechie and Wyman 1992; Montgomery et al. 1995; Schuett-Hames et al. 1999). The minimum length defining LWD, however, has less agreement. Bilby (1984) suggests that any piece shorter than 2 m may be unstable; Montgomery et al. (1995) considered LWD to be any piece longer than 1 m; Oregon Department of Forestry (1995) requires a length double to that of the bankfull width. In this report, we specify minimum dimensions only where necessary for clarity.

Physical processes

Instream wood influences stream morphology and channel form, creating structural heterogeneity and thus fish habitat via pools, back eddies, side channels, alcoves, and increased channel sinuosity (Bisson et al. 1987, Spence et al. 1996). LWD deposited in the active channel and floodplain provides sites for vegetation colonization, forest island growth and coalescence, and forest floodplain development (Fetherston et al. 1995; Bilby and Bisson 1998; Latterell and Naiman 2007).

The linkage of pool formation to instream wood is omnipresent in the literature. In general, the presence of wood increases the quantity and quality of pools that provide habitat for aquatic organisms (Bilby and Bisson 1998, Nakamura and Swanson 1994). Wood is also important for energy dissipation (Angermeier and Karr 1984, McMahon and Hartman 1989) and sediment retention (Fox 2003, O'Conner 1986).

Chemical processes

LWD provides an important source of organic matter to the stream. Wood provides favorable instream biological conditions for nutrient loading (Naiman and Sedell 1979; Wei and Kimmins 1998), and it provides nutrients and food sources directly to aquatic biota (Bilby and Likens 1980; Bisson et al. 1987). Several types of organic matter pass regularly from forests to streams; leaf litter and woody debris, in particular, are important sources of carbon for stream ecosystems (Malanson and Kupfer 1993).

Wood also traps nutrients in streams by intercepting and capturing organic material such as leaves, needles, and small woody debris (Bilby and Likens 1980). This material serves as an important food source for invertebrates in the stream (Wallace et al. 1995), which ultimately generates food for salmonids. Organic nutrients in Pacific Northwest stream ecosystems can be locally dominated by salmon carcasses in systems with large anadromous fish runs, and LWD has an important function in the retention of those carcasses (Cederholm et al. 1989; Spence et al. 1996).

Biological processes

The integration of physical and chemical influences makes LWD a key ecosystem component for stream organisms, particularly fish and notably anadromous salmon. Wood has been ubiquitous in temperate Pacific Northwest freshwater systems throughout the recent evolutionary history of salmon (Pess et al. 2003), and its role is significant at every life stage. In addition to the physical and chemical benefits mentioned above, wood also provides cover to facilitate juvenile rearing and downstream migration (Murphy et al. 1984, Bisson et al. 1987, Everest and Chapman 1972). Wood cover also reduces predation (Bilby 1984). The evidence is overwhelming that anadromous salmon have evolved in consort with abundant LWD in the rivers and streams of the Pacific Northwest, and that the presence of LWD is a key element of their continued survival.

Loss of LWD in large rivers

In contrast to the multiple causes of low modern LWD loads in small streams, changes in LWD occurrence in the region's largest rivers has a simple explanation. Removal of wood from the rivers of lowland western Washington streams was a major, well-documented endeavor from the late nineteenth century through the mid-twentieth century (Collins et al. 2002). The early part of this period demanded the greatest efforts, because clearcutting of the Lowland was well underway during this time and the rivers were the primary highway for the transport of logs to the mill. A choked waterway was worthless for this purpose. Even after this period of intense logging, removal of hundreds or even thousands of snags per year by the U.S Army Corps of Engineers continued in the region's rivers through at least 1960 (Collins et al. 2003). Since that time, further such work by state and local road engineering and public works departments has continued but left a much more fragmented, and currently unassembled, record of removal rates.

The consequences of these activities on the occurrence of LWD in lowland rivers of western Washington are best described by comparisons between modern rivers of the Puget Lowland, of which many run for hundreds or thousands of meters with almost no LWD except what is sporadically encountered along the banks.

1. Reference Conditions

1.1. Introduction

The goal of the reference condition evaluation is to characterize the historical occurrences and functions of LWD in the lower mainstem Lewis River. Historical conditions are defined as those conditions existing prior to European settlement. During and following this period, substantial alterations occurred to the river and the watershed that changed the processes of wood delivery and retention in river channels. Throughout this document, 'reference' and 'historical' may be used interchangeably and should be assumed to represent the conditions that existed in the past or would exist currently in the absence of significant human intervention.

The reference condition analysis is accomplished first through a review of historical conditions in streams of western Washington, spanning both the range of riverine systems and the variety of topographic settings across the region. Secondly, we evaluate the applicability of these occurrences for the lower Lewis River and provide an estimate of the historical quantities and distribution of wood in the lower Lewis between tidal influence (river mile [RM] 10) and Merwin Dam (RM 19.5).

These analyses set the framework for characterizing the range of functions that instream LWD might be expected to perform in the Lewis River. The results will help to define targets for future stream-rehabilitation projects that acknowledge the physical and biological changes imposed on rivers and streams by various land uses.

1.1.1. Ecology of Western Washington riparian forests

Regionally, climatic variations control the characteristics of forest vegetation, which in turn influence the nature of the riparian vegetation and thus the long-term source of inputs of LWD to rivers and streams.

Western Washington forests, the product of our wet temperate climate, are typically dense, naturally long-lived conifers and among the largest biomasses in the world (Franklin and Dyrness 1973). Basal areas can exceed 100 m^2/ha, tree heights reach 50-75 m at maturity, and some species live beyond 800 years (Franklin and Dyrness 1973). Tree mortality is generally continuous through forest life-histories (Franklin et al. 2002).

Most of the Lewis River Watershed is dominated by either *Tsuga heterophylla* (Western hemlock) forest zones (<800 m), or at higher elevations the *Abies amabilis* (Pacific Silver fir) or *Tsuga mertensiana* (Mountain hemlock) forest zones.

In the Western Hemlock zone, which characterizes the lower Lewis River area, dominant tree species are the Western hemlock with Douglas fir co-dominant (Agee 1993), but large areas are often occupied almost exclusively by Douglas fir (Franklin and Dyrness 1973). Fire frequency intervals are generally less than 750 years, although ignitions from Native Americans may have increased this frequency in some areas (Agee 1992). Spies and Franklin (1991) reported that the average stem densities of Douglas fir (>100 cm diameter at breast height) in late-successional stands ranged from 18-29 trees/ha.

There are significant distinctions between upland and riparian forest stands. Naiman et al. (1998) reported that the basal area of riparian forests is generally as great as or greater than that of upland forests due to high rates of biomass production as a result of moisture, nutrients, and temperature gradients. Riparian forests often promote deciduous seral species regeneration in response to channel-associated disturbances (Naiman et al. 1998). Collins et al. (2003) tallied the occurrence of tree species along the major rivers of western Washington as reported in surveyors' notes from the mid- to late 19th century; they found an average of 84% hardwood species by stem count and about 55% by biomass, particularly from the presence of red alder (*Alnus rubra*). This contrasted to the dominance of Douglas fir and Western Hemlock on adjacent upland terraces.

The age of riparian forests has a strong influence on instream large woody debris. Fox (2003) found that instream wood volumes in streams with older riparian stands (>550 years) were approximately double that of younger stands. Similar trends were found when looking at the number of wood pieces, except for in the youngest forest age class (<=150 years old), where piece numbers were similar to older stands. This suggests that stem-exclusion processes provide large initial inputs of wood over the first 150 years but that wood recruitment (piece number and volume) is relatively low until stands mature and then begin to senesce over the next 400 years (Fox 2003).

1.1.2. Sources and variability of instream LWD

There are several means by which LWD finds its way into a stream. At the reach scale, trees can fall directly into a channel due to bole breakage or by being uprooted. These are often the result of various forms of chronic tree mortality such as suppression or exclusion of stems by overcrowding, wind throw, disease, old age, and the result of fluvial processes such as channel avulsion or lateral migration and bank erosion. Other processes such as debris flows and snow avalanches can deliver trees into downstream channels from steeper parts of the channel network (Cushman 1981; Grant and Swanson 1995). The river can also exhume buried wood within floodplains (Fetherston 1995; Latterell and Naiman 2007).

Instream LWD biomass is positively correlated to tree density (Bilby and Wasserman 1989), tree maturity (Bilby and Ward 1991; Rot et al. 2000), and the percent of conifers (Harmon et al. 1986). Source distance is correlated to tree height (McDade et al.1990; Robison and Beschta 1990), but McDade et al. (1990) could not attribute 47.7% of identified wood pieces to an adjacent riparian source—thus nearly half of the instream wood may be routed in from upstream sources. Clearly, instream wood loads are dynamic and fluctuate according to various natural processes at the reach and watershed scale. The following paragraphs elaborate on these processes.

Geomorphic influences

Channel size influences the quantity of instream wood, but few studies have systematically explored that variability. In streams draining basins fully unaffected by human activity (i.e. no timber harvest or other management, except regional fire suppression), Bilby and Ward (1989) found that mean length and diameter of wood pieces increased as channel width increased but that the number of pieces declined with increasing channel width. Their frequencies of instream wood decreased by almost an order of magnitude, ranging from 0.8 pieces/m in the smallest channels to 0.1 pieces/m in their largest systems. Over a broader range of channel sizes, Fox (2001)[1] found an increase in LWD piece numbers and volumes as channels increase in width: 0.38 pieces/m in the smallest channels (>0-6 m BFW) and 2.08 pieces/m in the largest rivers (30-100 m BFW).

Fox (2001) observed that small channels, and confined channels of any size, are likely to obtain a significant proportion of riparian trees for instream wood by bole breakage and passive tree mortality, rather than by active recruitment such as lateral migration or channel avulsion common to larger rivers. He observed that confined reaches often had resistant banks, which likely slow the rate of avulsion as compared to banks composed of unconsolidated material or floodplain sediments. Due to the resistance to lateral migration, trees adjacent to these channels are afforded greater intervals between disturbances and thus have the potential to grow older and perhaps larger. As a result, confined channels often have greater potential to recruit fewer but larger trees than unconfined channels, where lateral migration across the floodplain limits tree growth.

Natural disturbance

Instream wood loads vary over space and through time due to an array of natural disturbance processes. Wood accumulations thus are not constant but rather fluctuate with disturbance cycles. The amount of instream wood, therefore, represents the time since the last disturbance and conditions during the recovery period. Four types of disturbances commonly found in forested streams of western Washington are discussed below:

---

[1] The studies of Fox (2001, 2003, 2007) were conducted in basins relatively unaffected by anthropogenic disturbance These basins are characterized by forests that are loosely termed as “old-growth”, which also meet the following criteria: 1) no part of the basin upstream of the survey site was ever logged using forest practices commonly employed since European settlement, 2) the basin upstream of the survey site contains no roads or human-made modifications to the landscape that potentially could affect the hydrology, slope stability, or other factors potentially affecting the natural processes of wood recruitment and transport in streams. These basins will hereafter be referred to simply as natural or “unmanaged basins”, although it can be acknowledged that some basins are “managed” to remain pristine, and may also include fire suppression.

***Fire*—**Not only can fires directly contribute wood during the fires themselves, but because fire affects forest age, fires also affect the future size and quantity of wood that is available for recruitment to stream channels. Fires do not burn forests evenly and often result in patches of burned areas interspersed with unburned areas. Thus, natural systems with intact fire regimes often have riparian zones with trees in a range of sizes that are available for instream recruitment.

***Floods*—**Floods recruit LWD by bank erosion and channel avulsion, and by entraining wood stored in floodplains. High flows associated with floods increase the shear stress and buoyancy on instream wood and carry wood downstream or perhaps completely out of the system. Despite the potential mobilization of wood due to floods, Fox (2001) found that floods had little influence on the overall instream wood loads of natural systems, for two likely reasons. First, much of the wood in these systems has previously resisted mobility during large floods, as broadly interpreted by the overall age of pieces (as estimated by decay classifications) found in the channel during the surveys. Even small pieces of wood in some streams had advanced decay that suggests these pieces have prevailed within the system despite floods. Second, floods may replace wood flushed from a system with newly recruited trees. For both reasons, a net loss of wood from floods may not occur in unmanaged basins. In contrast, heavily managed watersheds with altered hydrologic regimes may have increased transport of wood without commensurate recruitment due to hardened banks, or conversely the suppression of peak discharges by flood-control dams may be sufficient in itself to reduce or eliminate most recruitment altogether.

***Debris flows and landslides*—**Debris flows and landslides influence the quantity, quality, and distribution of instream wood. This often-violent mobilization of material may either transport wood out of a reach or bring in new wood from upstream sources. Debris flows tend to deposit wood on slopes of 5-10% gradient (Ikeya 1981; Costa 1984; Benda and Cundy 1990; Fox 2001) and remove it from streams with gradients >10% (Fox 2001). In older forests, large standing trees and instream logs can retard debris flow propagation and reduce the distance that it travels, compared to debris flows in more intensively managed forests (Coho and Burges 1993).

***Snow avalanches*—**Snow avalanches are natural channel process that recruit wood into streams (Keller and Swanson 1979) and influence the riparian vegetation (Fetherston et al. 1995). Snow avalanches are most common in small headwater channels within the snow zone (Keller and Swanson 1979). Although not a significant process in most of the channels in the lower Lewis River watershed, it is potentially a significant upstream source of LWD that eventually moves lower into the channel network during historic conditions.

***Windthrow*—**Windthrow is a significant source of LWD recruitment to the stream (Lienkamper and Swanson 1987; Robison and Beschta 1990). In old-growth riparian forests, windthrow does not topple whole trees as much as it recruits a greater proportion of branches and treetops to the channel than in younger riparian stands, especially in areas prone to strong winds or heavy snowfall (Bisson et al. 1987). However, windthrow accelerates mortality in riparian areas abutting newly harvested forests, disrupting the rate of recruitment to streams (Grizzel and Wolff 1998).

1.1.3. Regional patterns of historic wood quantity and distribution

The following literature review provides a description of the number, volume, spatial distribution, organization, and other characteristics of wood we expect to find in natural, unmanaged watersheds. In its historic state, we would expect the Lewis River to reflect similar patterns of wood loading and conditions as indicated in broader studies in western Washington.

Historic accounts of instream wood

Historically, wild anadromous fish stocks evolved with stream systems that were obstructed by fallen trees, beaver dams, and vegetation growing in and beside the channels (Sedell and Luchessa 1981). Using historical data, journal accounts, and a relatively undisturbed reach of the Nisqually River, Collins et al. (2002) determined that wood loads in some lowland Puget Sound rivers were ten to over a hundred times greater prior to European settlement.

On an examination of the Stillaguamish River made in August 1879, the Army's Robert A. Habersham reported:

> "….From the head of tide-water to the forks, 17 miles, the current is rapid, and the channel, which is from 125 to 200 feet wide, much obstructed by snags and trees embedded in the bottom, and at six points completely closed by rafts, which have diverted the current so as to cut out minor channels, forming small islands.…The snags are numerous and large, and so deeply imbedded in the bottom that a steam snag-boat would be required for five or six months to open a channel 100 feet wide…" [U.S. War Department 1881 *in* Collins et al. 2002)

The presence of wood and large jams influenced channel meandering and width to a great degree. As R.H. Thomson reported from the Puyallup River (in Roberts 1920):

> "The presence of drift and the constant formation of jams prevents the maintenance of a permanent channel. These jams force the river from one side to the other and cause the river to erode a very wide channel. As an example of this might be mentioned that portion of the river between the point of emergence from the foothills and a point 4,000 feet below the Northern Pacific bridge, where the channel ranges in width from 1,000 to 2,500 feet. In the lower river the cutting is continually occurring on the outside of all sharp bend, with a result that the channel has a width of from 1,000 to 1,500 feet in many places."

The amount of wood was so abundant and well-lodged into riverbeds that logging and upstream settlement was stymied until settlers and the Army Engineers could pull, blast, and cut wood from rivers in the 1870s-1890s (Sedell and Luchessa 1981). Collins et al. (2002) found reports between 1889 and 1909 that the annual maximum diameter of removed logs ranged from 3.6 to 5.3 m (U.S. War Department 1889–1909), based on snagboat captain's records and confirmed by engineers' observations (e.g., U.S. War Department 1895).

Quantities of LWD

Regional factors influence the quantities of instream wood. This is because regional differences affect the composition and character of riparian vegetation, which is turn dictates the species composition, numbers, size, and volume of LWD recruited to the channel (Grette 1985, Bilby and Ward 1991, Bilby and Bisson 1998, Fox 2001).

Geomorphic factors such as channel size, gradient, confinement, bedform, origin, and reach morphology also influence instream wood quantities. Fox (2001) reported that in all but the smallest basins (<4 km^2), more wood volume was observed in confined alluvial channels as compared to confined bedrock channels. In basins draining 70 km^2 or more, streams originating from glacial sources have more wood volume per 100 m than streams fed predominantly with snowmelt and rain (Fox 2001). This may be related to the larger number of side channels in streams originating from glacial sources. Montgomery and Buffington (1997) and Fox (2001) also found that pool/riffle channels commonly exhibit greater volume per 100 m than plane-bed, step-pool, or cascade morphologies.

Based on data from unmanaged western Hemlock forests, which is the dominant forest type in the Lewis River basin, observed LWD quantities are given in Table 1, using data from fully unmanaged watersheds (see footnote on page ##). The wood values presented in Table 1 are based on region (western Washington) and bankfull width classes. Fox and Bolton (2007) found that the number and volumes found in streams were not only a function of region and bank-full width, but are also influenced by other geomorphic factors in basins relatively unaffected by anthropogenic disturbance. These authors developed Ordinary Least Squares (OLS) regressions including covariates of bankfull width, forest type, bedform, gradient, and confinement along with several combinations of interaction. The inclusion of these variables more accurately estimates wood numbers and volumes based on specific regional and geomorphic influences.

Quantities of Key Pieces

‘Key pieces’ or ‘key members’ of wood are proportionately large individual logs that function to provide the primary catalysts for smaller wood retention and jam formation. These pieces are independently stable and resist entrainment by moderate floods. The Washington Forest Practices Board (WFPB 1997) defines key pieces as:

> “a log and/or root wad that is:
> 1. independently stable in the stream bankfull width (not functionally held by another factor, i.e., pinned by another log, buried, trapped against a rock or bed form), and
> 2. retaining (or has the potential to retain) other pieces of organic debris.”

The size of a key piece thus varies by channel size, where the fluvial and buoyant forces dictate stability. The length and diameter of key pieces are factors influencing buoyancy and mobility. The WFPB established a size definition for an array of channel sizes based on the work of Fox (1994); however, these criteria only apply to channels with a bank-full width less than 20 m. Fox (2001) expanded these size criteria for larger streams based on field data from Washington State.

Although some dimensional combinations (independent of root wads) may influence piece stability more than others as they interact with channel shape, we assume that piece volume provides a reasonable representation of both length and diameter proportions factored into stability determinations. Fox (2001) also assessed the presence of root wads in combination with key piece size to determine their influence on stability, and has factored those findings into key piece definitions.

A summary of key piece volume definitions and key piece numbers developed by Fox (2001) are also provided in Table 1.

Table 1. Summary of percentile distribution statistics for instream wood quantities and volumes according to BFW classes for undisturbed western Washington watersheds. LWD is defined as a piece >10 cm diameter and >2 m in length. Volumes are estimated by Πr2L where L is the piece length, and r is the piece radius at the mid-point. n= the number of reaches sampled. Source: Fox (2001).

LWD Piece Quantity: Number of Pieces Per 100 m of Channel Length

BFW Class	75th Percentile	Median	25th Percentile	Standard Deviation	Range	n
0-20 ft (0-6 m)	38	29	26	16	68	19
>20-100 ft (6-30 m)	63	52	29	33	132	43
>100-330 ft (30-100 m)	208	106	57	127	4353	16

LWD Volume: Cubic Meters Per 100 m of Channel Length

BFW Class	75th Percentile	Median	25th Percentile	Standard Deviation	Range	n
0-30 m	99	51	28	62	285	62
>30-100 m	317	93	44	201	750	16

Key Piece Quantity: Number of Pieces Per 100 m of Channel Length

BFW Class	75th Percentile	Median	25th Percentile	Standard Deviation	Range	n
0-10 m	11	6	4	6	26	38
>10-100 m	4	1.3	1	3	18	40

Minimum Piece Volume to Define Key Pieces (all regions)

Bankfull Width Class	Minimum Piece Volume (m^3)
0-5 m	1*
>5-10 m	2.5*
>10-15 m	6*
>15-20 m	9*
>20-30 m	9.75
>30-50 m	10.5**
>50-100 m	10.75**

* Existing WFPB (1997) definitions ** Wood piece must have an attached root wad.

Jam formation and channel size

Wood spatial distribution varies between small and large channels. Many researchers (e.g. Keller and Swanson 1979, Bilby and Bisson 1998) have observed that wood becomes more clumped as streams become larger. Fox (2003) reports that the percent of wood allocated to larger group sizes increases with channel size (i.e. larger channels have larger jams). With each greater channel size class, the percent distribution of LWD shifts to larger group size classes, as depicted by the shift in the median in Figure 1. The percentages in wood volumes are also similar in terms of allocations to each group. In small channels (BFW≤5 m), 70% of wood pieces were distributed into groups of 9 or less, with the most frequent distribution of pieces occurring in groups of one (32%); however, in channels >50-100 m BFW, only 19% of wood pieces were distributed into groups of 9 or less, with 81% distributed in groups of 10 or more. In channels >50-100 m BFW, the most frequent distribution of LWD pieces occurred in groups of 200 or more (24%). Most notably, the median shift in LWD distribution from small groups (<10 pieces) to large groups (≥10 pieces) occurs when channels reach merely 5 m BFW and greater (Figure 1).

Piece size distributions in jams

Piece size distribution within log jams varies in quantities but is fairly uniform in terms of proportions in undisturbed watersheds. Fox (2003) reports LWD pieces >70 cm diameter averaged approximately 4% per jam, pieces 50-70 cm diameter averaged approximately 10% per jam, pieces 20-50 cm diameter averaged approximately 41%, and pieces 10-20 cm diameter averaged approximately 45%. These proportions did not differ significantly based on jam size.

Fox (2003) found that the quantity of racked members versus key pieces varies depending on channel size. In general, larger streams have more racked members per key piece. In streams with bankfull widths of 50 to 100 meters, the median number of racked members to key pieces ranged from approximately 6 to 25, depending on the number of key pieces in a jam. The upper range of racked pieces to key pieces exceeded 85. Regression equations relating number of racked pieces to key pieces can be found in Fox (2003) for a variety of channel width classes.

Lateral position of LWD

The magnitude of fluvial forces, as indicated by channel size, likely influences the lateral distribution of LWD in the channel. Fox (2003) reports that 1) the percent of LWD volume in the low-flow channel (Zone 1) decreased with increasing bankfull width, 2) the percent of LWD volume in the high-flow channel (Zone 2) increased with bankfull width, and 3) the proportion of wood that extends beyond the vertical boundary of bankfull (Zone 4) decreased with increasing bankfull width in unmanaged watersheds. These results are presented in Figure 2.

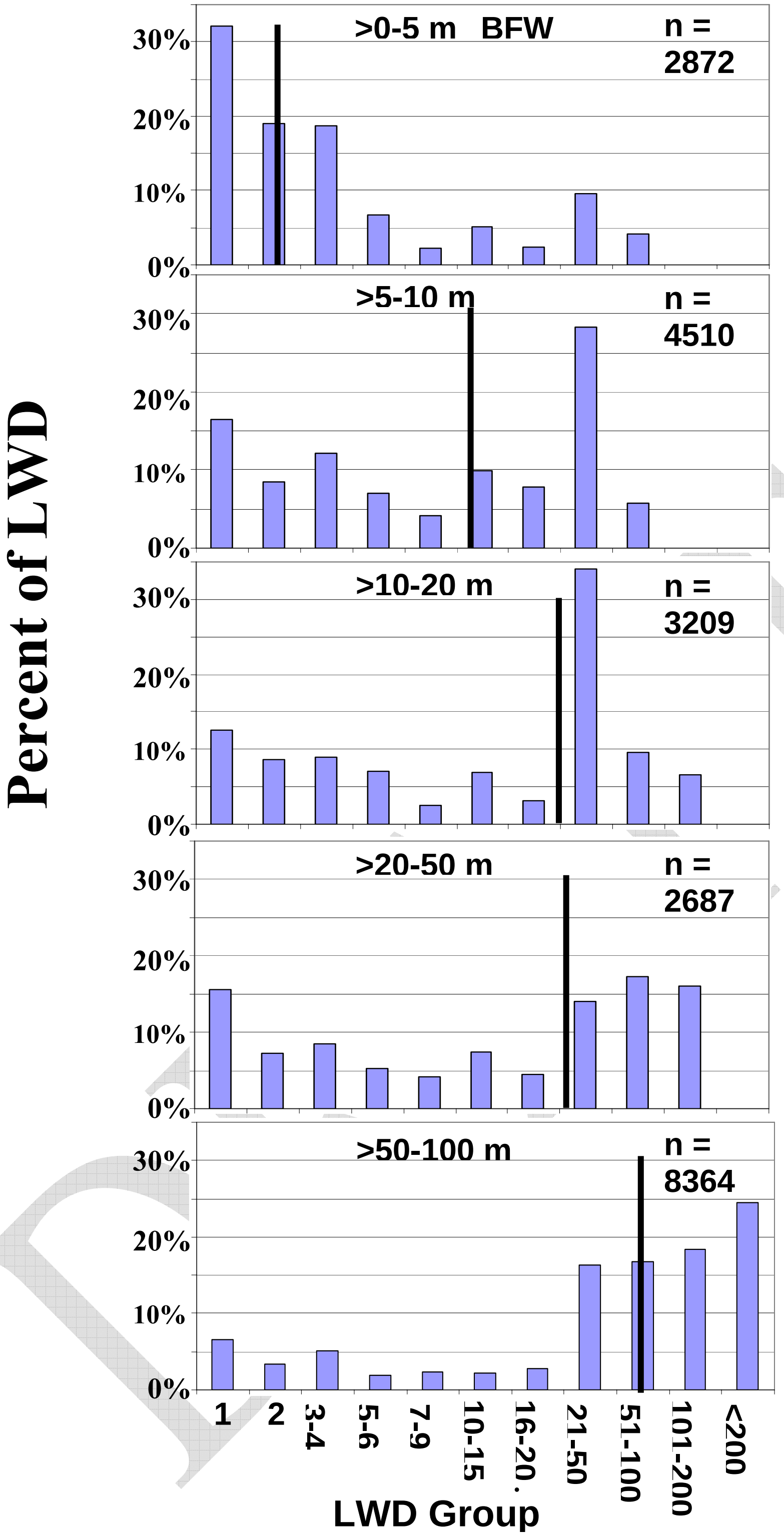


Figure 1. The percent distribution of LWD to group size class according to five bankfull width classes. The vertical bars in each chart represent the median. Source: Fox (2003).

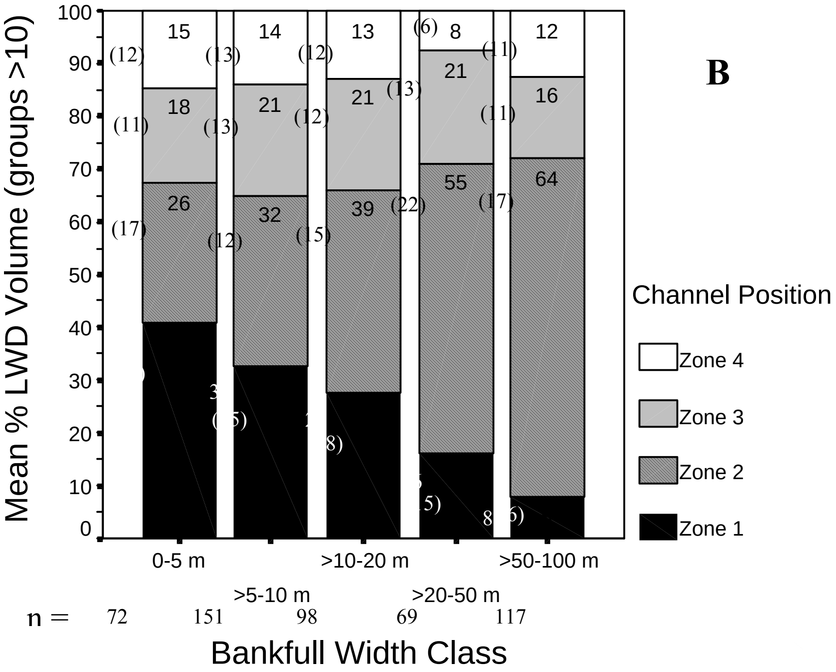


Figure 2. Comparison of the mean percent LWD volume by four lateral zone distributions according to five bankfull width classes. Only groups (accumulations) exceeding 10 pieces LWD are included. Zone 1 is the wetted low-flow channel, Zone 2 is above the wetted low-flow channel but below the horizontal axis of the bankfull channel, Zone 3 is above the high-flow channel but within the vertical confines of bankfull, and Zone 4 is laterally beyond the bankfull width. Zone definitions are from Schuett-Hames (1999). The numbers in parentheses are the standard deviations, and n = the number of LWD groups. Source: Fox (2003).

LWD Piece Orientation

Fox (2003) found that LWD piece orientations are influenced by channel size and the presence of an attached rootwad. With increasing channel size, the proportion of pieces oriented parallel to the channel increases while the pieces perpendicular to the channel decreases. Additionally, Fox (2003) reports that as channel size increased, LWD pieces with rootwads had a significantly greater probability to orient parallel to the flow with the large end upstream than pieces without rootwads; however, in the small channels (BFW< 10m), pieces with rootwads were more frequently oriented perpendicularly to the channel compared to pieces without rootwads.

LWD Length Distributions

Fox (2003) found that LWD lengths per diameter class varied between LWD group sizes in unmanaged forested watersheds. With greater diameter class, LWD had greater median lengths in all LWD group size classes. Regression analyses suggest that as group size increases, piece lengths within each diameter class also increase.

LWD in small vs. large channels

Although small channels have less wood per unit length than large channels, LWD in small channels has a particularly critical role in storing sediment. In the absence of wood, channels scoured to bedrock by a debris flow may lack the capacity to store sediment and can persist in a bedrock state (Massong and Montgomery 2000; May and Gresswell 2001). May and Gresswell (2001) concluded that with an adequate supply of wood, low-order channels can store large volumes of sediment in the interval between debris flows and can function as one of the dominant storage reservoirs for sediment in the channel network. Fox (2003) observed that sediment storage by wood residing in the low flow channel was highest in small streams. Wood in small channels is also a strong determinant of geomorphic channel type at moderate stream gradients, controlling whether a forced pool-riffle or plane bed channel morphology will occur along particular reaches of a channel network and determining much of the physical attributes of the channel of ecological significance.

Large channels and their associated floodplains also are geomorphically influenced by wood, but in different ways. Compared to smaller streams, Bilby and Bisson (1998) observed that wood has less effect on channel form in larger streams. LWD jam accumulations located in the floodplain, however, reduce flood velocities and provide foci for side channel development, sediment storage, and valley formation (Prestegaard and Folk 2001). Wallerstein et al. (1997) found that debris-induced sediment retention tends to exceed debris-induced channel scour, indicating that debris jams generally achieve net sediment storage along the channel reach.

The above studies provide a basic context in which to frame further refinement of historic wood conditions in the Lewis River watershed. Our objectives are to utilize and expound on this information to develop more refined estimates of the historic wood loading characteristics for the lower Lewis River.

LWD Jam Types

Types of wood accumulations vary by channel size. In small channels, wood can be found virtually anywhere in and along the channel. Small streams lack the power and buoyant forces to mobilize wood, creating a nearly random distribution dictated by riparian inputs: wood tends to remain in the locations “as it fell,” and attrition of these pieces often occurs only during large episodic events (floods, debris flows, dam-break floods, etc.) or through decay. In large rivers that are many times as wide as LWD is long, fluvial forces primarily organize wood accumulations. Abbe and Montgomery (1996) categorize these large-river LWD accumulations based on the presence or absence of key members, source and recruitment mechanism of the key members, jam architecture, the jam’s geomorphic effects, and patterns of vegetation on or adjacent to the jam. Abbe et al. (2003) describe these accumulation types and their functions as follows:

Bar apex jams tend to be catalyzed by a single key piece oriented parallel to the channel with the root-wad upstream. These jams accumulate racked members and small woody debris against the upstream end of the root wad, slowing the water velocity to enable sand and gravel deposition along the key piece, ultimately forming a gravel bar. Bar apex jams are responsible for much of the channel complexity, including island and pool formation, in these systems. They are a principal mechanism contributing to the formation of anastomosing channel systems in the Pacific Northwest.

Step jams or multi-log weirs are found in relatively small channels with a wide range of gradients. These structures can account for more than 80% of the head loss in a channel (Abbe 2000) and provide almost all of the hydraulic and habitat diversity within the channels where they occur.

Valley jams are large, complex grade-control structures found in steep channels with gradients ranging from 2 to over 20%. These structures are typically composed of tens or hundreds of trees.

Bench jams are typically found in relatively small, steep channels where large logs become wedged into the margins of a channel and create local revetments protecting floodplain deposits and vegetation.

Flow deflection jams are found in relatively large channels with moderate gradients. These structures form initially when large trees that do are not readily entrained by moderate floods (key members or key pieces) fall into the river and deflect flow. But with time these structures become integrated into a new river bank and are thus classified as bank protection or revetment-type structures as opposed to flow-diversion structures.

Meander jams are large flow-diversion channels found in large alluvial rivers. As the channel laterally migrates, meander jams form hard points or resistance along the bank, thus impeding bank erosion (Daniels and Rhoads 2001). These structures offer a model that has been successfully emulated to limit channel migration, protect banks, and restore aquatic habitat and riparian forests (e.g., Abbe et al. 2003). Natural meander jams are a principal cause of channel avulsions in Pacific Northwest rivers, in that arrest of gradual lateral migration can eventually lead to abrupt channel switching in natural systems.

1.2. Methods

1.2.1. Historical LWD Conditions in Lower River

There are several methods to approach the issue of quantifying historic wood conditions in the Lewis River. The lower reaches of the Lewis River, particularly in the tidally influenced areas, were likely depositional areas for entrained wood originating upstream. This is described best in the Army Corps of Engineers reports provided in section 0. Resource managers are less likely to restore the lower river to these conditions due to adverse implications to navigation as well as the likely impossible task of finding and distributing enough wood to emulate these conditions. As such, quantifying the vast amounts of wood in these depositional reaches is both difficult and impractical to use in a meaningful manner for restoration purposes. Alternatively, we can reference modern studies that have quantified wood loads found in unmanaged rivers, where fluvial processes have established a dynamic equilibrium of wood conditions. Research that has assessed wood retention in unmanaged rivers with similar regional and geomorphological processes as the Lewis River potentially offer a reasonable approach to estimating historic wood conditions for practical management purposes.

LWD Numbers and Volumes

The recent work of Fox and Bolton (2007) produced a linear regression that is intended to customize wood predictions to any stream in the forested landscape of Washington based on multiple regional and geomorphic variables. The variables exhibiting the most influence on predicting wood numbers and volumes, the interaction relationships, and corresponding regression coefficients, error, t-values, and probabilities are provided in Fox and

Bolton (2007). The variables used in the regression include bankfull width, channel slope, forest type, and confinement class. It should be noted that although earlier findings of Fox (2001) suggest that forest age is a significant predictor in wood numbers and volumes, Fox and Bolton (2007) found that forest type is highly correlated with stand age. Therefore, age is adequately represented by forest type, which is reflective of disparate fire regimes and climate influences.

For the purpose of this analysis, LWD is defined as a piece having a minimum length of 2 meters and a minimum mid-point diameter of 10 cm, following the methods of the aforementioned researchers.

Wood Spatial Distribution

The organization of wood has important implications on the success of restoration projects that utilize wood placement. The findings of Fox (2003) serve as a useful method to spatially characterize wood that was likely found in the Lewis based on discrete channel types. Since spatial organization was not significantly influenced by regional attributes but rather by fluvial forces, it follows that using channel width classes similar in size to those found in the Lewis River reaches is a reasonable approach. For example, Fox (2003) found that as channels become larger, wood tends to organize into ‘clumps’ or jams. For a river the size of the Lewis, an estimated 81% of the wood is distributed into jams, and the most frequent distribution of LWD pieces occurs in groups of 200 or more. The relationships of Fox (2003) discussed in Section 1.1.3 also provide a useful tool for spatial predictions.

Bankfull widths were estimated using tools of ArcGIS® on color 2006 orthophotographs, where an average of widths were taken at approximately 200 ft. intervals. Bankfull edges were determined as well as possible based on vegetative indicators following the methods of Pleus and Schuett-Hames (1998). Confinement classes were based on the methods of Pleus and Schuett-Hames (1998), where a confined channel has a valley bottom width less than two channel widths, a moderately confined channel has a valley bottom width between two and four channel widths, and a unconfined channel has a valley bottom width greater than four channel widths. Reach delineations were obtained from Ecosystem Diagnostic Treatment (EDT) modeling on the lower Lewis River conducted by WDFW for the Lower Columbia Salmon and Steelhead Recovery Plan (LCFRB 2004, *and revisions in prep.*).

1.2.2. Historical Basin Supply

Historical basin supply is defined here as the amount of wood that was delivered to the lower Lewis below the current Merwin Dam site prior to European settlement. During and following this period, substantial alterations occurred to the river and the watershed that changed the magnitude, frequency, and size of wood delivered to the lower river. There is very little available information regarding the historical wood supply. A discussion of potential quantities and origins of wood is included based on known processes of wood delivery in unmanaged systems, and with reference to basin-scale wood budgets that have been conducted in the Pacific Northwest.

1.3. Results and Discussion

1.3.1. Historic LWD Conditions in Lower River

Using the best available science, we estimated the historic LWD conditions for the Lewis River. These ranges can be used: (1) to assess current instream wood condition and ratings for the evaluation of stream habitat; (2) to identify target wood loads for restoration, enhancement, and mitigation projects; and (3) to develop land-use regulations, ordinances, and laws to protect and manage salmon habitat.

Number of pieces of LWD

Regression estimates for predicted wood quantities produced values within or slightly below the percentile ranges found by Fox (2001) for western Washington. Expected values of historic wood numbers ranged from 45 to 78 pieces per 100 lineal meters of channel. The disparity in values largely stemmed from the confinement of the reach, where less confined reaches had more wood than confined reaches, largely a factor of the storage of wood in side channels common in less confined rivers. The complete output is presented in Table 2.

Table 2. Lewis River Reach descriptions and the results of the regression model predictions for historic numbers of pieces of LWD expected by reach. For comparison, also shown are the percentile ranges of wood loading for Western Hemlock forests (applicable to this section of the Lewis River) from Fox (2001). BFW = bankfull width.

Reach Descriptions and characteristics					*Number of LWD[1] Pieces*		
Reach	**Description**	**Reach Length (m)**	**BFW (m)**	**Confinement**	**Central distribution (25th percentile, median, 75th percentile) for number of LWD pieces/100m([2])**	**Regression-predicted LWD Pieces/100m (considering all significant variables)[3]**	**Total number of pieces expected for the entire reach**
Lewis 3	Robinson Cr. to Ross Cr.	1159	140	Moderately Confined	57/ 106/ 208	78	906
Lewis 4a	Ross Cr. to Hayes. Cr.	1749	117	Moderately Confined	57/ 106/ 208	73	1271
Lewis 4b	Hayes Cr. to Staples Cr.	2100	114	Moderately Confined	57/ 106/ 208	72	1509
Lewis 4c	Staples Cr. to Houghton Cr./ Kenyon Cr.	374	89	Moderately Confined	57/ 106/ 208	65	243
Lewis 5	Houghton Cr./ Kenyon Cr. to Johnson Cr.	4538	96	Moderately Confined	57/ 106/ 208	67	3045
Lewis 6	Johnson Cr. to Cedar Cr.	644	77	Confined	57/ 106/ 208	45	291
Lewis 7a	Cedar Cr. to Colvin Cr.	933	89	Confined	57/ 106/ 208	47	439

Lewis 7b	Colvin Cr. to Merwin Dam	5198	83	Confined	57/ 106/ 208	46	2398

[1] Minimum size of 10 cm midpoint diameter and 2m in length (Schuett-Hames et al. 1999)
[2] Based on percentile distributions for bankfull width category (Fox and Bolton 2007)
[3] Based on multiple regressions using bankfull width, forest type, gradient, confinement, & bedform (Fox and Bolton 2007)

Volumes of LWD

Regression estimates for predicted wood volumes produced values within the percentile ranges found by Fox (2001) for western Washington. Expected values of historic wood numbers ranged from 75 to 144 cubic meters per 100 lineal meters of channel. Note that the confined reaches are predicted to have greater volumes in confined reaches than in the moderately confined reaches, despite the fact that they have less numbers as shown in Table 2. This is likely due to the fact that confined reaches constrict the channel at high flows and create greater forces on elements such as wood. Therefore, wood stable enough to withstand these forces likely needs to be larger on the average than wood pieces in less confined reaches. The complete output for wood volume is presented in Table 3.

Table 3. Lewis River Reach descriptions and the results of the regression model predictions for historic volume of LWD expected by reach. For comparison, also shown are the percentile ranges of wood volume for Western Hemlock forests (applicable to this section of the Lewis River) from Fox (2001). BFW = bankfull width.

Reach Descriptions and characteristics					***LWD[1] Volume***		
Reach	**Description**	**Reach Length (m)**	**BFW (m)**	**Confinement**	**Central distribution (25th percentile, median, 75th percentile) for volume of LWD pieces (m^3)/100m ([2])**	**Regression-predicted LWD Volume (m^3)/100m (considering all significant variables)[3]**	**Total volume of LWD pieces expected for the entire reach**
Lewis 3	Robinson Cr. to Ross Cr.	1159	140	Moderately Confined	44/ 93/ 317	85	989
Lewis 4a	Ross Cr. to Hayes. Cr.	1749	117	Moderately Confined	44/ 93/ 317	81	1417
Lewis 4b	Hayes Cr. to Staples Cr.	2100	114	Moderately Confined	44/ 93/ 317	80	1688
Lewis 4c	Staples Cr. to Houghton Cr./ Kenyon Cr.	374	89	Moderately Confined	44/ 93/ 317	75	280
Lewis 5	Houghton Cr./ Kenyon Cr. to Johnson Cr.	4538	96	Moderately Confined	44/ 93/ 317	77	3474
Lewis 6	Johnson Cr. to Cedar Cr.	644	77	Confined	44/ 93/ 317	138	891
Lewis 7a	Cedar Cr. to Colvin Cr.	933	89	Confined	44/ 93/ 317	144	1348

Lewis 7b	Colvin Cr. to Merwin Dam	5198	83	Confined	44/ 93/ 317	142	7359

[1] Minimum size of 10 cm midpoint diameter and 2m in length (Schuett-Hames et al. 1999)
[2] Based on percentile distributions for bankfull width category (Fox and Bolton 2007)
[3] Based on multiple regressions using bankfull width, forest type, gradient, confinement, & bedform (Fox and Bolton 2007)

Key Pieces of LWD

Due to the fact that the regressions of Fox and Bolton (2007) do not extend to key pieces, we defaulted to the ranges of key pieces found by Fox (2001). Note that for the Lewis River, a key piece is defined by a piece having a minimum bole volume of 10.75 m^3 and an attached root wad according to the work of Fox (2001). The proportions per Lewis reach are thus calculated for key pieces and presented in Table 4.

Table 4. Lewis River Reach descriptions and percentile ranges predictions for historic volume of LWD expected by reach. For comparison, also shown are the percentile ranges of wood volume for Western Hemlock forests (applicable to this section of the Lewis River) from Fox (2001). BFW = bankfull width.

Reach Descriptions and characteristics					***Key Piece[1] Quantity***	
Reach	**Description**	**Reach Length (m)**	**BFW (m)**	**Confinement**	**Central distribution (25th percentile, median, 75th percentile) for number of Key pieces/100m**	**Total number of key pieces expected for the entire reach**
Lewis 3	Robinson Cr. to Ross Cr.	1159	140	2	1/ 1.3/ 4	15
Lewis 4a	Ross Cr. to Hayes. Cr.	1749	117	2	1/ 1.3/ 4	45
Lewis 4b	Hayes Cr. to Staples Cr.	2100	114	2	1/ 1.3/ 4	54
Lewis 4c	Staples Cr. to Houghton Cr./ Kenyon Cr.	374	89	2	1/ 1.3/ 4	10
Lewis 5	Houghton Cr./ Kenyon Cr. to Johnson Cr.	4538	96	2	1/ 1.3/ 4	59
Lewis 6	Johnson Cr. to Cedar Cr.	644	77	1	1/ 1.3/ 4	8
Lewis 7a	Cedar Cr. to Colvin Cr.	933	89	1	1/ 1.3/ 4	12
Lewis 7b	Colvin Cr. to Merwin Dam	5198	83	1	1/ 1.3/ 4	68

[1] Key pieces are defined as a log with a root wad having a bole volume equal or greater than 10.75 m^3.

Wood Distribution

From Figure 1Figure 2, we can estimate the historic distribution of wood in the Lewis. Although some of the lower reaches are greater than 100m in bankfull width, we believe that using the classes of 50-100 m BFW are the best available and will provide a reasonable estimate on wood distributions. The following bullets summarize the probable spatial distribution of wood in the historical lower Lewis River.

- Approximately 24% of the wood numbers and volumes (from Table 2 and Table 3) would be grouped into jams having 200 or more pieces and approximately 50% of the wood would be located in jams ranging from 21 to 200 pieces (Figure 1). The remaining 26% would be located in smaller accumulations or as individual pieces.

- Approximately 64% of the wood volume in jams would be located in the high-flow channel and 8% would be located in the low-flow channel (Figure 2).

- Piece diameter and length distributions would follow the relationships found in Fox (2003).

- The proportion of racked members per key pieces in jams can be predicted by the regression equation:

$$y = 24.8x + 3.36$$

where y is the number of racked members and x is the number of key pieces in a jam. The median number of racked members per key piece is approximately 25 but could potentially reach as high as 85.

1.3.2. Historical Basin Supply

Historical supply of LWD to the lower river would have originated from local riparian inputs as well as from fluvial transport from the mainstem and from lower river tributaries. The various input sources and potential quantities are discussed below.

Local sources

In the unconfined reaches below the canyon, local inputs would most likely have been dominated by bank erosion inputs as opposed to natural mortality. This is typical in large mainstem rivers with lateral channel adjustment (O'Connor et al. 2003, Martin and Benda 2001). In the canyon reaches, however, lateral channel adjustment would have been uncommon and local inputs would most likely have been contributed via natural mortality of riparian trees and from landslides originating on the canyon walls. Several landslide areas that had contributed wood were observed on a field survey of the lower river on August 10, 2007. It is likely that this process of mass wasting in the canyon has not changed significantly from historical conditions; however, the size of logs contributed has likely been reduced due to younger stand ages resulting from past timber harvest.

Other studies may provide insight into the relative contribution of wood from various sources. Murphy and Koski (1989) recorded 60% of LWD inputs from bank erosion, and 20% each from windthrow and mortality in large alluvial channels. Almost all trees were from within 30 m of the bank and for the large alluvial streams, 62% originated from the bank itself (<1 m). In the WTS-3 study, the number of trees leaning out over the bank, appearing to be susceptible to recruitment in the near future, were counted. The total number of these "potential" trees along 9.7 miles (15.6 km) of stream was 66. If we assume all of these trees would enter the stream within the next year, then based on Murphy and Koski's values for proportionality of sources (bank erosion vs. windthrow vs. mortality), we can predict that 11.3 trees/mi/yr (7 trees/km/yr) will be recruited from riparian areas. Of course, this would be under existing conditions; recruitment would most likely have been greater under historical conditions because of greater bank erosion due to a non-regulated hydro-system and due to the presence of large jams that initiate erosion events.

Upriver and tributary sources

The quantity of fluvially transported wood into the lower river from the mainstem would have been high in the historical condition, given the large size and transport capacity of the mainstem Lewis. Given historical flow conditions, channel widths and depths would have been more than adequate to efficiently transport large logs during frequent flood events (1-2 year recurrence interval). Assuming an historical (unregulated) 1-year flow of 18,000 cfs (obtained from figure 11.1-2 in FLD-1), and using cross-section data described in Section 2.3.2 below, width of flow exceeds 400 feet and average depth is nearly 9 feet. Thus, even at flows as frequent as an annual peak flow, a considerable amount of wood would be expected to enter the lower river as fluvially transported wood from upstream; and much of this wood would be transported through the lower Lewis and out into the Columbia River. Wood would be retained in the lower river on bar deposits and at channel boundaries at meander bends. Retention would most likely occur during the descending limb of the hydrograph when flows are shallower and transport capacity decreases.

There have been several LWD studies conducted in the Pacific Northwest that can help approximate the historical quantity of wood supplied to the lower river. Most studies of wood abundance in rivers have measured recruitment rates into stream channels and not basin yield (a.k.a. flux) at a point along the stream, especially for a basin the size of the Lewis. However, a couple of studies have generated relevant basin yield estimates; these include an assessment of LWD on the Baker River in northern Washington (R2 Resource Consultants 2002) and wood budgeting conducted on Game Creek in southeast Alaska (Martin and Benda 2001). In the Baker River study, in addition to wood budgeting on the Baker River itself, staff from several PNW hydropower operations were asked to provide estimates of average annual wood supplies to reservoirs; from which wood yields per basin area were calculated in order to compare to Baker River estimates. The range of all available values (including Baker River and Game Creek) is 0.3 to 3.5 m^3/km^2/year. All of these systems have had impacts from past timber harvest that would affect wood recruitment rates. If we assume the upper end of the range for historical LWD yield from the Lewis Basin, we obtain an average annual wood supply of approximately 6,600 m^3/year contributed to the lower river based on the watershed area of 1,868 at the current Merwin Dam site (RM 19.5).

In addition to wood transported from the Lewis mainstem, tributary sources would also contribute LWD to the lower river. The largest tributary is Cedar Creek, which enters the Lewis at RM 15.7. Cedar Creek has a drainage area of approximately 145 km^2. Assuming the same per basin area contribution of LWD in the historical condition (3.5 m^3/km^2/year), the Cedar Creek Basin would contribute an additional 500 m^3 of LWD to the lower river downstream of RM 15.7. Most of the other tributaries are considerably smaller and would likely have only contributed negligible amounts of LWD to the Lewis.

Mount Saint Helens impacts

The 1980 eruption of Mount Saint Helens contributed a massive amount of debris to the Upper Lewis River system, most of which ended up in Swift Reservoir (Figure 3). Nearly 80 km of stream along the Muddy River, Smith Creek, Swift Creek, and in the Pine Creek Basin were affected by lahars during the eruption (Martinson et al 1984). These massive mud and debris flows cleared all the standing timber in their paths; contributing an estimated 18 million cubic yards of water, mud, and debris to Swift Reservoir (Tilling et al. 1990).

In the decade following the eruption, storm flows continued to transport large amounts of wood that remained within the flood channels of the impacted streams. As part of a long-term stream sediment monitoring project, Dinehart (1997) noted that unlike typical Northwest streams, abundant fluvial transported wood persisted even after peak flows subsided. He reported that the amount of debris transported during storms decreased to “nuisance” levels a few years following the eruption.

1.3.3. Recommendations for Restoration

Instream wood is merely one indicator of stream and salmonid habitat conditions; however, it is a stream feature that has been readily manipulated by channel, riparian, and watershed management. Wood quantities are also fairly easily manipulated to rehabilitate or “jumpstart” habitat recovery through restoration programs. In these endeavors, whether it is for riparian management or for targeted rehabilitation efforts, management objectives should consider historical reference conditions in order to provide context for management.

The regression predictions and percentile distributions for LWD numbers, volumes, and key piece quantities discussed previously (Table 2 through Table 4) provide a range of reference conditions for each reach of the Lewis River and can be used in habitat restoration, enhancement, evaluation, regulation, and perhaps to develop riparian recruitment objectives. These predicted values represent a wide range of conditions in unmanaged systems (except for fire suppression) and therefore provide a reference for restoring the natural quantities and variability (i.e. heterogeneity) of wood. Attaining historical wood conditions will be impossible given the amount of alteration in the Lewis Basin; however, moving wood quantities closer to historical quantities is a laudable goal that will increase the quality of habitats to which aquatic organisms have adapted.

To achieve functional wood quantities in the Lewis may initially require setting objectives above the mean or median of the historical range (e.g. using the 75th percentile or perhaps 25% more than the regression-predicted value) in order to expedite recovery and resemble the central tendencies of natural/ unmanaged conditions. This also applies to key piece quantities, where rather than using the median value of 1.3 pieces per 100 m of channel, a better restoration objective may be to use 4 pieces/100 m (the 75th percentile). Because of the reduction in the availability of key piece size material, measures will have to be taken to sufficiently anchor wood in the channel to facilitated jam formation. Through this approach, recovery of habitat conditions can be more expeditiously achieved.

2. Existing and Projected Conditions

2.1. Overview

2.1.1. Management impacts

The current LWD conditions in the Lewis below Merwin are a result of several interrelated factors. These include early clearing and snagging operations, use of the river for log transport in the early-to-mid 1900s, construction of the mainstem Lewis dams, regulation of flows through the hydrosystem, timber harvest, and more recent wood removals to facilitate boat navigation.

Historical clearing, snagging, and log transport

Significant work in improving the Lewis River for navigation began in 1899 with the passage of the Rivers and Harbors Act (Willingham 1983). Between 1899 and 1913, considerable improvements were made to the lower river from the mouth up to the confluence of the East Fork (RM 3.5). This work included bank clearing, snagging, and scraping of shoals. In 1913, congress authorized funds to clear the 12.5 miles upstream of Woodland. The project was completed in 1928. In their assessment of log transport on rivers of the Northwest, Sedell and Duval (1985) note that there was a period of active log drives on the Lewis between 1900 and 1920, when as much as 150,000 tons of wood a year were rafted down the river. The upstream extent of these drives was not noted, and it is possible that most of the log drives occurred downstream of Eagle Island. Based on these reports, it is assumed that most of the wood in the river below Merwin Dam was removed by 1928; although much of it was possibly removed earlier to facilitate log drives.

Hydro-regulation

Merwin Dam, the first of the hydropower dams on the Lewis River, was constructed in 1931 at RM 19.5. For the first 7 years following dam construction, flows that exceeded the single unit capacity of about 4,000 cfs were passed over the dam, along with accompanying wood debris (WTS-1). After this period, higher floods were contained and wood debris was captured in the reservoir, essentially ceasing the downstream transport of wood to the lower river. Wood counts from 1938 aerial photography show very few pieces of wood in the lower river, suggesting that any transported wood either flushed through the lower river or was cleaned out by snagging operations. In 1953, Yale Dam was constructed at RM 34 and Swift Dam was constructed in 1958 at RM 48. Currently, most of the wood from the upper basin collects in Swift Reservoir and is removed annually by PacifiCorp.

The blockage of LWD transport by the hydro-system has the largest impact on wood abundance in the lower river. Wood that is currently supplied to the lower river comes only from local sources and from tributary inputs. Historically, the vast majority of instream wood would have originated from upstream source areas and would have accumulated as large jams in the lower river. Today, local riparian, valley wall, and tributary inputs appear to contribute only small amounts of stable LWD to the river.

Changes to the flow regime have likely had a significant impact on the ability of the lower river to retain wood. Hydro-regulation has had a number of different impacts on the flow regime of the river. These include a reduction in spring flows as reservoirs are filled in the spring, an increase in summer base flows, and an increase in fall flows as reservoirs are drained in anticipation of winter rains. The most important change with respect to wood retention, however, is the impact that hydro-regulation has had on the winter high flows that are capable of moving LWD. Compared to pre-dam conditions (Merwin, the first dam, was constructed in 1931), flows capable of entraining key piece size material have decreased because of the dampening effect of the reservoirs on peak flows (see Figure 7). Whereas this change probably reduces the amount of channel erosion, which is important for wood recruitment from the lower river, it would increase the chance that wood will be retained in the lower river and increases the probable longevity of wood in the channel.

Interruption of bed material transport

The cessation of bed material transport due to the hydro-system has likely had impacts on the ability of the lower river to retain LWD. Previous investigations have demonstrated that, unlike other dam controlled systems, the Lewis below Merwin has retained an abundant amount of spawning-sized gravel and cobble despite cessation of transport through the hydro-system (Stillwater Sciences 2006). This is believed to be largely due to the presence of coarse lag deposits below the dam from a large flood in 1933. This coarse material is large enough to resist significant downstream movement given the current flow regime, but it is still within the size range of spawning-sized material. Even though new material is not entering the lower river from upstream, the existing material is staying in place and is continuing to provide ample spawning habitat. The material below the dam has also not become overly armored or embedded. This may, in part, be due to bed disturbance by large spawning Chinook salmon.

Although spawning conditions may remain favorable below the dam, wood retention has likely decreased as a consequence of bed material transport interruption. A decrease in bed material from upstream serves to decrease bar formation and the natural channel dynamics that occur as a result. This impact not only decreases lateral channel boundary erosion, which is important for wood recruitment, but it also reduces the availability of bedforms, such as point bars and mid-channel bars, which are important sites for wood recruitment and jam formation. The changes to channel dynamics are likely greater in the lower reaches (RM 10 to 15) than in the canyon reaches (RM 15 to 19.5), because of the natural confinement and high energy for sediment transport in the canyon. Changes to bar formation in the lower reaches can be seen by observing the historical photo record. Following the flood of record in 1933, large newly formed bars were created and are clearly visible on the 1938 aerial photographs (Stillwater Sciences 2006). Since this time, relatively minor bar formation has occurred (the 1996 flood re-arranged some spawning areas and created some active bars) and the bars from the 1933 flood have become encroached with vegetation. The reduction in bar formation is likely due to a number factors, including the lack of a large flood comparable to 1933, the flood dampening affect of hydro-regulation, and the cessation of bed material transport due to the dams.

Channel alterations

There have only been a few major channel alterations above the downstream end of Eagle Island. These are related to placement of fill material, gravel mining, and natural channel processes. There are a few instances of rip-rap and other bank hardening. The largest area of channel alteration is near RM 12.5, just downstream of the golf course boat ramp. Due to concerns with erosion of the highway on the right (north) bank, a levee was constructed to halt the river's northward migration and keep it away from the highway embankment. This work likely occurred following a high flow event in 1946 (WTS-3 relicensing report). There is now a large backwater area behind the levee in the old river channel. This channel alteration has served to simplify the channel in this location and has likely decreased the potential for LWD retention in this area. Instead of a meandering planform with cycles of bar formation and erosion, there is now a straightened section of channel comprised primarily of glide habitat. There is also less potential for recruitment of riparian trees from the levee, which is comprised of large rock and is mostly devoid of large trees.

Other channel alterations have occurred in the lower river, in particular near RM 15 and at the upstream end of the south Eagle Island channel (WTS-3 relicensing report-pg3-47). Channel changes at these locations are partially related to past gravel mining of bar deposits, which affected the location of the main channel.

Recreation and navigation

There has been clearing of wood over the years to facilitate boat navigation, although it is difficult to quantify the specific amounts. Clearing of wood from the river can have a significant impact on the amount of wood in the river, especially because there is so little existing wood in the channel.

2.1.2. Mechanisms of wood delivery

Wood delivery to the reservoirs

Wood delivered to the reservoirs comes from fluvial transport from tributaries as well as from the lakeshores themselves. The amount delivered from tributary sources is dependent on stream size (transport capacity), stand conditions, bank erosion rates, and the frequency of disturbance events such as debris torrents, landslides, fires, and volcanic eruption (Benda et al. 2003). The amount delivered from lakeshore sources depends on stand conditions, the presence of landslide-prone areas, lakeshore erosion rates, and the amount of lakeshore perimeter.

The presence of the reservoirs, as opposed to the historical river channels, affects the amount of wood supplied to the system. The reservoirs have abundant margin areas, which increases the length of bank that may contribute LWD through natural mortality, bank erosion, and landslides. LWD budgeting on the Baker River in northern Washington estimated that the reservoirs increase wood recruitment rates to at least 4-times that which would occur in the absence of the reservoirs; this was attributed primarily to an increase in recruitment from reservoir margins (R2 Resource Consultants 2002). Although there may be an increase in recruitment due to creation of extensive reservoir margin areas, there is a reduction in recruitment from streambank erosion that would have occurred in the historical stream channels. The reduction of recruitment from bank erosion is likely significant in the Lewis given the size and character of the now inundated channels. Bank erosion rates increase with an increase in channel width (Benda et al. 2003) and bank erosion has been shown to be a dominant factor for wood recruitment in large lowland rivers in the region (O'Connor et al. 2003).

There is the potential for wood delivery from volcanic activity on Mount Saint Helens. These inputs would likely originate from mudslides in the streams draining the mountain (Pine, Swift, Muddy, Smith) but could also originate from more catastrophic events such as the debris avalanche that occurred on the north side of the mountain during the 1980 eruption.

The eruptive history of Mount Saint Helens is probably the best indicator of its future eruptive potential. The mountain has had nine eruptive periods over the past 50,000 years, one as recently as the first half of the 1800s (Tilling et al. 1990). Based on this past activity, and intermittent activity since the 1980 eruption, it is probable that volcanic activity will continue to impact debris loading conditions in the Lewis River basin over the next few hundred years.

Figure 3. Mud and debris at the upper end of Swift Reservoir following the 1980 Mount Saint Helens eruption.

Wood delivery to the lower river

Riparian inputs come from bank erosion, blowdown, landslides, and tree fall from mortality; however, river and riparian forest management has altered these dynamics. Significant clearing of riparian timber can be observed on the 1938 photos, resulting in younger forest stands than would have dominated the river in the historic condition. The riparian areas are currently made up of deciduous and mixed deciduous/conifer riparian forest stands with canopy heights less than 100 ft tall (TER-9). Development along the lower river has also had a major impact on potential tree recruitment. Over 42% of the 6 miles downstream of Merwin Dam have been impacted by development, including roadways, residential development, and a golf course (TER-9). Due to past harvest of riparian trees and development impacts, riparian inputs contribute less and smaller trees than would have been contributed historically. Despite these impacts, an aquatic habitat survey in 2000 counted 66 "potential" recruitment trees that were leaning over the bankfull channel. Most of these (68%) were located in the confined reaches upstream of RM 15.5 (WTS-3).

In the confined reaches (RM 15.5 – 19.5), LWD inputs also come from landslides originating on the high valley walls. Two such landslides that had recently contributed large wood were observed during a field survey of the canyon reach (Figure 4).

Figure 4. Photos of small landslides contributing LWD to the channel at RM 16.4 (left photo) and RM 18.8 (right photo). Photos taken August 10, 2007.

Tributary inputs come from the larger tributaries that enter the mainstem below Merwin Dam, including primarily Cedar Creek. Tributary sources have been reduced due to past riparian impacts along tributary channels. They likely supply only small quantities of small material except during the largest of floods. The size of material capable of being supplied by tributary channels is likely readily transported through the lower mainstem. However, under restored conditions, this material may provide important quantities of small to medium-sized pieces that contribute to jams.

A number of factors affect the ability of the river, under its current channel, sediment, and flow regime, to retain LWD. These factors are discussed below, followed by an examination of current hydraulic conditions and how these have changed from historical conditions with respect to wood retention.

2.1.3. LWD quantities in the lower river

Total pieces LWD

Past studies have quantified instream large wood conditions in the river below Merwin Dam. These include the Stream Channel Morphology and Aquatic Habitat Study (WTS-3 Relicensing Report) and a habitat assessment conducted by the Lower Columbia Fish Recovery Board (LCFRB 2004). A summary of these results is provided in Table 5. The estimated reference condition wood quantities are included as a comparison. The lower number of pieces recorded as part of the WTS-3 study is possibly due to a larger size criteria for qualifying as a LWD piece (see Table 5). Pieces of LWD per mile range from 9.6 to 39 pieces per mile. In comparison, historical density of wood is estimated at 743 pieces per mile for the confined reach and 1,129 pieces per mile for the unconfined reach.

Table 5. Pieces of LWD per mile from past studies. The historical reference numbers from this study are included for comparison.

Study	Confined (RM 15.5 – 19.5)	Unconfined (downstream of RM 15.5)
WTS-3 (2000)[1]	9.6	20.4
LCFRB (2004)[2]	NA	39
Reference Conditions (see Section 1.3.1)[2]	743	1,129

[1] *minimum size criteria: >30.5 cm diameter; >7.6 meters length*
[2] *minimum size criteria: >10 cm diameter; >2 meters length*

Key pieces LWD

A survey of the river was conducted on August 10, 2007 to measure large pieces that may be serving as key pieces under existing conditions. Only large pieces that were judged to be self-stabilized within the bankfull channel were recorded. The survey was facilitated by a boat although piece dimensions were measured on the ground wherever practicable. Measured piece characteristics included length, diameter (dbh and midpoint), rootwad diameter (if applicable), location in the channel, and species (if possible).

A total of 18 pieces were surveyed (Table 6). The average piece length was 70 feet, average diameter at breast height (dbh) was 3 feet, average volume was 8m^3, and average root wad diameter (for those with rootwads) was 8.5 feet. Over 80% of the pieces had attached rootwads. Many of these pieces are below the 10.75 m^3 key piece threshold that has been assumed necessary in the Lewis; however, several of them are coupled with others (i.e. intertwined root masses), which increases their functional size. Most of the pieces surveyed were located in zone 2, which is outside the low-flow channel but within the bankfull channel (see Schuett-Hames et al. 1999 for more information on zone definitions).

Despite being self-stabilized in the bankfull channel, it is unlikely that many of the surveyed pieces would be capable of functioning as jam-forming key members, especially within the active, low-flow channel. Based on site observations, it is possible that many of the pieces had deposited on bars at the receding limb of a storm hydrograph. The combination of large piece size (>10.75m^3) with attached rootwad that is believed to be necessary to act as key jam-forming pieces only occurred on 22% (4 out of 18) of the surveyed pieces.

Table 6. Results of key piece survey on August 10, 2007, River mile 10-19.

EDT Reach	River Mile	Length (ft)	DBH (ft)	Mid Pt Diam (ft)	Root Wad Diam (ft)	Species	Zone	Comments
7B	17.5	96	3.5	1.8	9	cottonwood	2	
7B	17.1	129	3.5	2.6	8.4	Douglas fir	2	Coupled with next one
7B	17.1	78	2.9	1.3	5.6	cedar	2	Coupled with previous one
7B	16.87	30		3.3	none	conifer	1	6' in zone 1
7B	16.4	60	3.0	1.6	9	big leaf maple	2	Contributed by landslide. Held in place by colluvium pile
7B	16.2	50		3.3	none	cedar	1	
7A	16.1	78	5.4	3.9	6	conifer	1	Key piece of small jam. Rootwad rounded off
7A	16	72	3.3	2.2	6	cedar	2	
7A	15.95	69	3.8	2.5	11.5	cedar	2	
6	15.3	66	2.3		10	cottonwood	2	Spanning Johnson Creek
5	13.4	63	2.7	1.3	11	alder	2	Coupled with next one
5	13.4	63	1.7	1.1	8	alder	2	Coupled with previous one
5	12.7	75	2.9	1.5	8	cottonwood	2	
4B	11.4	45	2.0	1.2	8	cottonwood	1	
4B	11.25	42		3.0	none	cottonwood	2-3	Key member of large jam up on bank
4B	11.27	80	2.0	0.7	5	unknown	1	
4A	10.7	114	3.6		11	cottonwood	1	
4A	10.1	84	3.9	2.6	12	cottonwood	1	

2.2. LWD Supply to Mainstem Reservoirs

2.2.1. Introduction

The supply of LWD to Merwin, Yale, and Swift Reservoirs represents the existing amount of wood that is supplied by the Lewis River watershed upstream of Merwin Dam. In the absence of the hydropower system, this is the amount of wood that would be expected to enter the lower mainstem below Merwin, assuming equilibrium wood storage conditions upstream. This amount of wood also represents the supply that would be available to the lower river if wood was routed around the hydrosystem or was made available for re-introduction through restoration efforts.

2.2.2. Methods

The current supply of wood from the upper basin (above Merwin Dam) was estimated through examination of the quantities of wood salvaged from the three mainstem reservoirs. PacifiCorp arranges for the salvage of reservoir wood in most years and disposes of the wood through either: 1) donation for fish and wildlife enhancement, 2) sale of merchantable timber, or 3) burning. The bulk of the salvage work is focused on Swift Reservoir, which is the uppermost reservoir and receives the most amount of wood material of the three reservoirs. Occasional salvage operations are also conducted on Merwin and Yale Reservoirs as needed based on wood conditions.

Consistent wood salvage records have not been kept, so estimates were derived through a combination of: 1) wood counts of current (2007) salvage from Swift Reservoir, 2) review of limited photos and wood estimates from previous years, and 3) personal experience and judgment of PacifiCorp staff.

The minimum size criteria to qualify as a piece of LWD is a diameter of at least 10 cm along 2 meters of length (Schuett-Hames et al. 1999). A key piece is further defined as a piece of LWD with a volume that exceeds 10.75m^3 (see Section 1.1.3 for more information on what qualifies as a key piece).

Volumes and piece size distributions were measured and estimated from this year's salvage at Swift Reservoir. Although a large amount of wood was recruited to the reservoir during the November 2006 flood, this year's salvage amount at Swift was believed to be typical of an average year's salvage (Kirk Naylor, personal communication). This is reasonable considering only 50-70% of the wood was removed due to limitations imposed by reservoir level changes. An estimate of average annual volume entering Swift was obtained by accounting for the number of years within the past 20 years that salvage operations occurred in the Reservoir.

Coarse approximations of wood quantities salvaged from Merwin and Yale Reservoirs were obtained from PacifiCorp staff and from historical photos. These values were combined with volume per basin area values obtained from Swift estimates in order to estimate the average annual amount of wood recruited to these reservoirs.

The size distribution of wood from the 2007 Swift salvage was assumed to represent the typical size distribution of wood supplied to the reservoirs under current basin conditions. The proportion of pieces meeting the size criteria of a key piece (>10.75 m^3) was determined from log measurements. The diameters of key pieces were measured and the average was calculated to facilitate comparisons with historical conditions.

Wood entering the reservoirs is assumed to represent the amount of wood that would be available to enter the lower river at Merwin in the absence of the hydropower system. This assumes equilibrium wood storage conditions between Merwin and the upper end of Swift Reservoir.

2.2.3. Results and discussion

The total volume of qualifying LWD (>10 cm diameter, >2 meters long) supplied to the three reservoirs was estimated at 2,093 m^3 (Table 7). This is slightly more than the estimated volume of LWD salvaged this year from Swift Reservoir (see Figure 5). The total rate of delivery is 1.12 m^3/km^2/yr. This value is within the range of estimates made in other Pacific Northwest Basins (R2 Resource Consultants 2002). Nearly 80% of the total wood supply ends up in Swift Reservoir, with approximately 10% supplied to each of the other reservoirs (see Table 7). The amount of wood per contributing area for Swift is nearly double that of Merwin and Yale. This is reasonable considering the larger acreage of Swift Reservoir (4,600 acres compared to 4,040 and 3,780 acres for Merwin and Yale, respectively) and the large volumes of wood contributions that would be expected to be delivered to Swift by the upper mainstem Lewis River.

Figure 5. Photo of wood salvaged from Swift Reservoir in summer 2007.

Based on the proportion of key pieces measured in the 2007 Swift Reservoir salvage, the average number of key pieces contributed to the reservoirs each year is estimated at just over 10, most (80%) ending up in Swift Reservoir. Average key piece diameter (dbh) is estimated at 1.1 meters.

Table 7. Estimated average annual LWD volumes (>10 cm diameter, > 2 meters long) contributed to each reservoir. These values should be viewed as approximations. The values are based on salvage counts, available documentation, and experience of PacifiCorp staff.

Reservoir	Contributing acreage	Total LWD volume (m^3/yr)	Delivery Rate m^3/km^2/yr	# of Key Pieces[1]/yr
Merwin	85,470	246	0.71	1.2
Yale	74,490	217	0.72	1.1
Swift	301,684	1,630	1.34	7.9
Totals	**461,645**	**2,093**	**1.12**	**10.2**

[1] *Key pieces are defined as those with volumes >10.75 cubic meters*

Compared to historical conditions, LWD supply has likely been reduced by at least 70% (assuming a historical supply of 6,600 m^3/yr, see Section 0), or even more depending on the assumptions used. Key piece supply has also decreased markedly. Based on the proportion of key pieces from the Fox (2001) dataset, key piece numbers would equal approximately 83 individual pieces a year given a total historical LWD volume of 6,600 m^3/yr. Key piece diameter has also decreased, from a historical average of 1.5 meters to a current average of 1.1 meters (Table 8).

Table 8. Current and historical key piece characteristics

	Current Conditions	Reference Conditions
Numbers of Key Pieces per year (>10.75 m^3)	10.2	83
Mean diameter of key pieces (>10.75 m^3) (m)	1.1	1.5

Although estimated LWD supply values are expressed as average annual values, the amount of wood supplied to the reservoirs fluctuates considerably from year to year (Naylor, pers comm.). In years with no significant flow events, contributions may be quite low, whereas in years with large events, such as 1996 and 2006, contributions may be very high due to the occurrence of numerous bank erosion events, debris torrents, landslides, and mobilization of instream LWD.

2.3. Projected Conditions in Lower River

2.3.1. Introduction

Projected retention of LWD in the lower river below Merwin refers to the ability of wood to self stabilize within the channel in the absence of artificial anchoring. This assessment is useful for identifying the potential for retention if the current supply of LWD were reintroduced to the lower river. It is also useful for identifying the anchoring requirements necessary for LWD in restoration efforts. This assessment was conducted by evaluating: 1) current channel geometry, 2) the piece sizes available in the current LWD supply, and 3) current hydrologic conditions.

2.3.2. Methods

Channel cross-section data are combined with flow data to describe the hydraulic conditions affecting wood retention and entrainment. Channel cross-sections were obtained for the Lewis River from past studies and from field surveys. Cross-sections were obtained at RM 19 (Ariel Gage – USGS data), RM 13.6 and 13.4 (past Inter-Fluve studies), and at RM 12.4 (new survey). The survey of the cross-section at RM 12.4 was conducted on August 10, 2007 using a total station survey instrument.

Flood frequency discharges, including an estimate of bankfull flow, were obtained from a combination of past studies, site observations, and cross-section analysis. At-a-station hydraulic analyses were performed for selected cross-sections using WinXSPro software (USDA 2005) in order to obtain channel geometry measures that affect wood transport.

The size of wood pieces used in the hydraulic analysis was obtained from the size of key pieces measured from the Swift Reservoir wood supply (see Section 2.2.3). As described in Section 1.1.3, key pieces for a channel the size of the lower Lewis are defined as having a volume greater than 10.75m^3. Only key pieces are considered in the hydraulic analysis because it is assumed that only pieces of at least this size are capable of self-stabilizing in the mainstem Lewis and serving as key members initiating jam formation. Smaller LWD material is unlikely to be retained in the river unless it impinges against existing key pieces or jams.

2.3.3. Results and discussion

Whether or not wood jams could form in the lower river is dependent on the availability of key pieces that are capable of being stable under current hydraulic conditions. There are two dominant factors typically affecting wood retention: 1) piece size, including diameter, length, and whether there is an attached rootwad, and 2) hydraulic conditions, including channel width and depth. Previous field and laboratory research has related wood movement to log and channel dimensions (Lienkaemper and Swanson 1987, Braudrick and Grant 2000, Abbe and Montgomery 2003). In general, smaller logs are more easily transported than larger logs. Log transport occurs more readily when logs are shorter than bankfull width (Lienkaemper and Swanson 1987), a condition that would be frequently encountered in the mainstem Lewis. Log diameter has also been shown to be a good predictor of wood movement, especially in wide channels where channel width exceeds log length. In theory, as the flow depth exceeds the depth at which the log floats (buoyant depth), it is more likely to become mobilized (Braudrick and Grant 2000). There are several other factors that can affect this dynamic, including channel form, the presence of bed obstructions, and whether or not the log is buried in bed sediments. One of the greatest factors, however, is the presence or absence of an attached rootwad. Rootwads cause considerable drag on the channel bed and serve to decrease the likelihood of entrainment. A study of log jams on the Queets River noted that the key members forming log jams had a diameter at least half the bankfull depth of the channel, and most of these (82%) had attached rootwads (Abbe and Montgomery 2003).

Due to the wide channel of the mainstem Lewis, where bankfull widths typically exceed 80 meters, diameter and presence of a rootwad are probably better predictors of wood stability than piece length, since piece length is nearly always shorter than channel width. Based on cross-section analysis and flow data, the ability of the current channel to retain wood was estimated by looking at the percentage of key pieces (>10.75 m^3) whose piece diameters exceed their entrainment depth over a range of flows. For this analysis, key piece sizes were obtained from the current supply of material entering Swift Reservoir (Section 2.2). Retention was assumed to be achieved when piece diameter exceeds 0.6 of the average flow depth, which is the average value for entrainment obtained from flume experiments carried out by Braudrick and Grant (2000). Figure 6 displays the results of this evaluation at a typical river cross section across a riffle at RM 13.6. In this case, at flows greater than approximately 10,000 cubic feet per second (cfs), less than 30% of the key pieces have diameters large enough to have a good chance of being retained in the channel. The increase in retention around 15,000 cfs is due to the river overtopping a floodplain terrace, thus decreasing the average channel depth and creating shallower flow areas where wood could be retained.

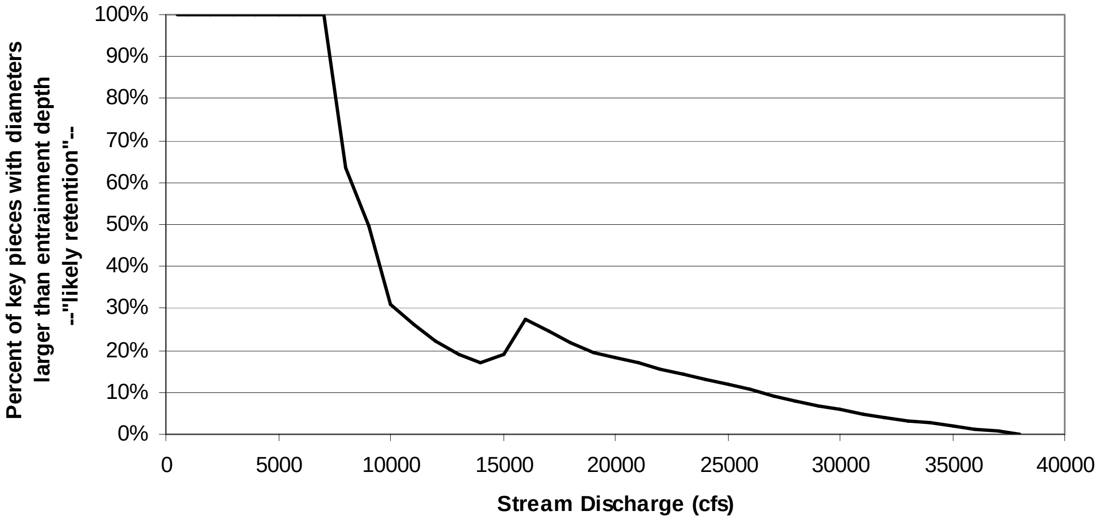


Figure 6. The percent of key pieces (>10.75m^3) (based on current basin supply) with diameters larger than entrainment depth at a range of flows. Typical riffle cross section at river mile 13.6. Retention (the opposite of entrainment) is assumed when piece diameter exceeds 0.6 of the average flow depth across the cross section (based on Braudrick and Grant 2000). The increased retention potential beginning at 14,000 cfs is due to overtopping of the floodplain terrace, which increases the amount of shallow depth area across the cross-section.

Considering that the available supply of key pieces may only be about 10 pieces per year (Section 2.2), if the wood supply were re-introduced to the lower river, the number of key pieces likely to remain in the channel during a large flow event is small. A 2-year recurrence interval flood of 22,000 cfs (see PacifiCorp, FLD-1) is likely to mobilize over 80% of the key pieces, leaving only a few pieces that are likely to be retained.

In our survey of large pieces currently within the bankfull channel (Section 2.1.3), the average diameter was approximately 1.0 meter and many of these pieces did not have attached rootwads. Considering that the average bankfull depth of the channel typically exceeds 2 meters, it is clear why most of these pieces were located high on gravel bars (zone 2) or were intertwined with other pieces, thus increasing their stability.

In the historical condition, piece retention would have been more frequent because of a larger number of key pieces and the availability of larger size classes. The change in hydrologic conditions, however, also must be taken into account. Compared to pre-dam river conditions, flow regulation has reduced the incidence of peak flows during the rainy season. This effect can be observed in the flow duration curve for the Lewis River at the USGS Ariel gage (RM 19) (Figure 7). The frequency of flows in the 10,000 to 24,000 cfs range has been reduced.

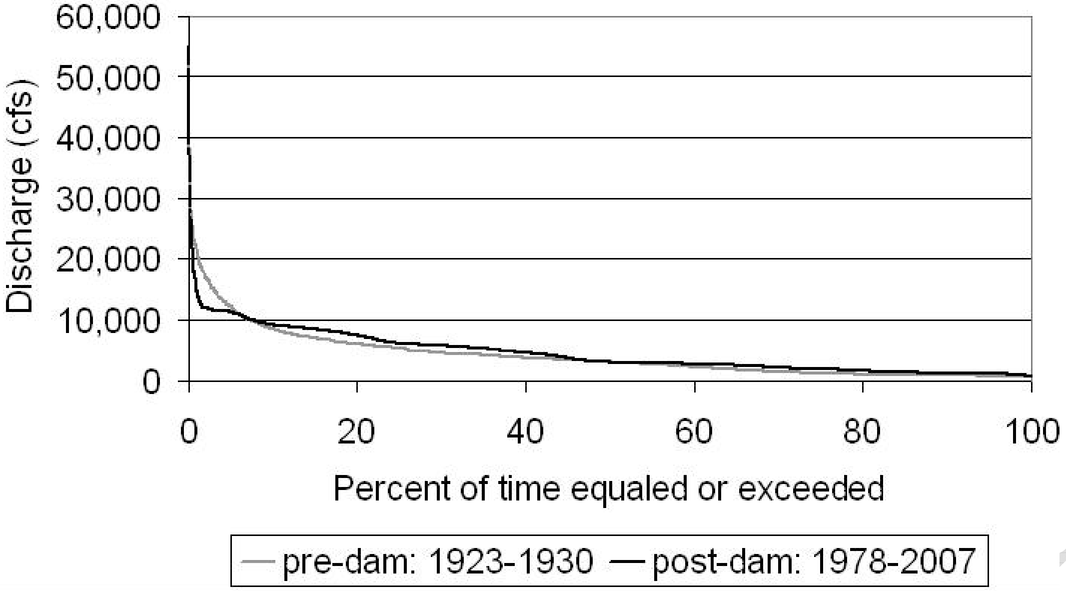


Figure 7. Flow duration curves for the pre-Merwin Dam and post-Merwin Dam conditions. The frequency of flows between 10,000 and 24,000 cfs have been reduced due to hydro-regulation.

The reduction in peak flows affects instream wood quantities in a number of ways. Reducing flood flows decreases the incidence of channel bank erosion and floodplain inundation, which reduces the recruitment of wood from the riparian zone. However, decreasing peaks would also have the effect of decreasing log entrainment within the channel; thus decreasing the likelihood that instream wood will be transported out of the system during floods.

In order to assess historical changes in wood transport conditions, both hydrologic changes and piece size changes were factored into hydraulic analysis at a sample cross section. The ratio of average piece diameter to average flow depth was plotted against flow for the historical and current conditions (Figure 8). The larger the piece diameter in relation to flow depth, the greater potential for retention in the channel. For this evaluation, the percentile flow is used in order to represent both historical and current flow conditions. Percentile flow represents the frequency of flow for the period prior to Merwin Dam construction in 1931 (historical) and the period spanning the last 30 years (current). This analysis demonstrates that in the historical condition, retention of wood was approximately 50% more likely than in the current condition, even despite the current reduction in peak flows.

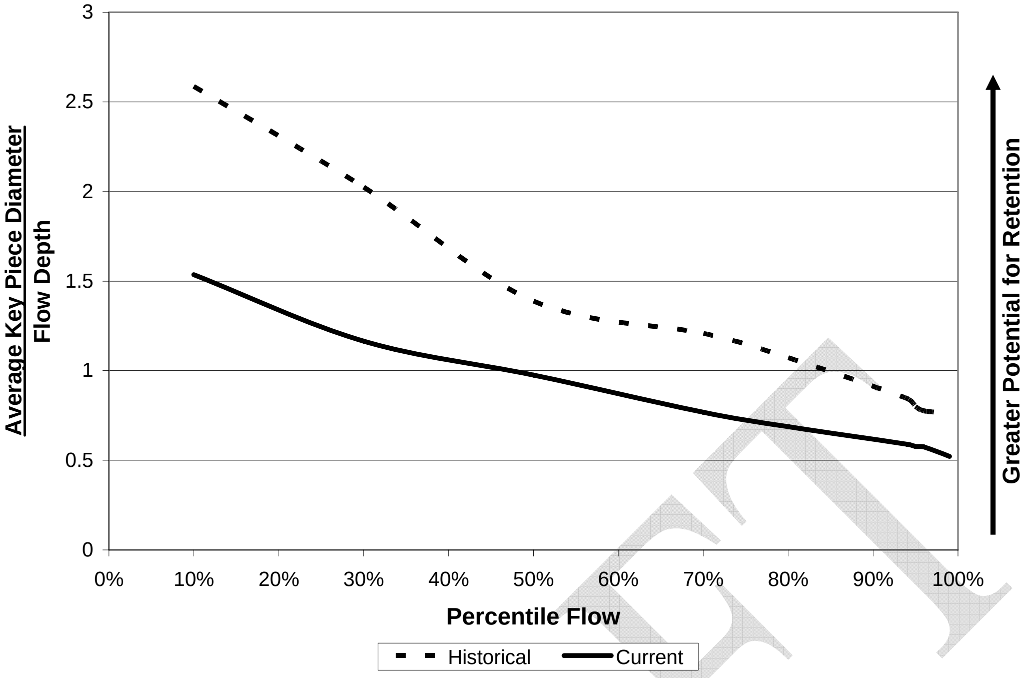


Figure 8. Ratio of average piece diameter to average flow depth plotted against flow for the historical and existing conditions. As flow depth decreases with respect to piece diameter, the potential for retention in the channel increases. Historical and current average piece diameters are 1.5 and 1.1 meters, respectively. Percentile flow is used because the flow regime is different for the historical (pre-Merwin Dam) and existing (last 30-years) condition. Percentile flow is the percentile flow using all average daily flows for the period (historical = Aug 1923 – July 1930; existing = Sept 1978 – Aug 2007). Thus, the 50% flow represents the median flow for the period and the 100% flow represents the greatest flow for the period.

2.3.4. Recommendations for Restoration

In summary, the decrease in peak flows (10,000 to 24,000 cfs) due to hydro-regulation has likely served to increase the likelihood of wood becoming retained in the channel, and also would decrease the likelihood of instream wood being entrained and washing out of the system. However, the dramatic reduction in key piece size and availability, compared to historical conditions, far outweighs the impact of flow alterations. Under current wood supply conditions, there simply are not enough key pieces of large enough size to contribute significantly to jam formation in the river, even if wood is routed around the hydrosystem. This has important implications for restoration efforts. Wood enhancement projects will need to provide adequate anchoring to ensure that wood remains in place long enough to fulfill project objectives. In natural systems, wood routinely washes out, but a renewed flux of wood would be available to replace it. Under current wood supply conditions, if wood washes out, there will be very little wood available to replace it. In the absence of adequate anchoring or an increase in a regular supply of wood of sufficient size, maintaining target wood levels would require continuous and repeated restoration effort.

3. LWD Project Opportunities

3.1. Introduction

Large woody debris restoration project opportunities and techniques were identified for the lower river between Merwin Dam and the downstream end of Eagle Island. Project recommendations were developed based on site observations, past experience of investigators, and with reference to the results of Tasks 1, 2, and 4 Considerations that should be taken into account in development of project opportunities are discussed below.

3.1.1. Reintroduction of existing basin wood supply

LWD supply to the lower river has been interrupted by the hydropower system, which includes Merwin, Yale, and Swift Dams and their associated reservoirs. Transport of wood around the system of dams and reservoirs would increase wood quantities to some extent in the lower river. Under this scenario, would quantities and characteristics would be similar to wood conditions that would be present in the hypothetical absence of the hydropower system and would be on par with other regional rivers that are unaffected by large dams. However, based on the evaluation of wood retention conducted in Section 2.3, most of this wood would be re-introduced to the lower river only to be transported out of the system entirely. This is primarily due to smaller sizes of available key pieces that are necessary to stabilize themselves in the channel and initiate jam formation. There is also much less wood in total that would be available to accumulate in jams and increase jam longevity. Wood that does happen to accumulate into jams would be susceptible to fluvial transport and export from the system during frequent (i.e. 1-2 year) flooding events, once again leaving the channel mostly devoid of wood.

If the objective is to establish greater LWD quantities over the long-term that will increase fish productivity, then simply transporting wood around the hydropower system may not be the most beneficial or efficient approach, based on the previous discussion. And this is not to mention the logistical constraints and timing issues that transporting wood would entail. A more efficient and beneficial strategy would involve the strategic placement of wood in the lower river using configurations and techniques to ensure wood stability. The entire upper basin wood supply (that which is contributed to the reservoirs) would potentially be available for this purpose.

Based on the above conclusions, the restoration project opportunities that are discussed herein are focused on strategic placement and anchoring of wood in the lower mainstem and associated side channels and off-channel areas. Wood anchoring can be accomplished via a variety of methods, including burial in sediments, stacking of wood in jams to increase mass, or use of natural or artificial ballast. Suggested anchoring methods for individual project opportunities are discussed in the project opportunities section.

3.1.2. LWD project design targets

The precise quantity, volume, and organization of wood needed by salmonids for successful production are not precisely known. Statistically sound studies to link instream wood loads and organization to salmonid production are unavailable; even if such a study were undertaken, it would be expensive and have high levels of uncertainty due to the multiple variables influencing salmon production. Due to the effect of past management practices on instream wood, impacted streams commonly display loadings well *below* the historic range, particularly in urban and agricultural settings. Thus, merely managing for the mean or median will not restore the natural ranges of heterogeneity across a watershed or a landscape. To pull the regional mean of wood loading closer to the historic condition while staying within the historic range, Fox et al. (2003) recommended using that part of the LWD distribution between the 25th and 75th percentiles to better reestablish central tendencies of natural distributions. Restablishing wood quantities to the 50th percentile in the lower Lewis would be a major undertaking due to the river's size, the lack of abundantly available LWD, the smaller size of available material, and social constraints. The recommended projects that are included below, in total, would represent only a fraction of the historical wood load. Thus, these projects should be viewed as a potential start to wood recovery in the system, with the assumption that future efforts will exceed these measures, all the while improving re-habilitation techniques through adaptive management.

3.1.3. Constraints on LWD project effectiveness

The rationale for restoration with wood must first evaluate recovery of degraded physical processes that contribute to the biological processes supporting salmonid habitat. For example, Cederholm et al. (1997b) concluded that there was little merit in taking efforts to add wood if the processes that deliver it are not on their way towards recovery. Secondly, site conditions and the choice of project objectives determine the prospects for using LWD. If project objectives are primarily for ecological improvement, then the sites that are likely to show the greatest biological response are those where physical disturbance of the channel is the greatest substantive impact and where recruitment potential from adjacent and upstream riparian areas is high. If these conditions are not met, LWD will be a necessary but insufficient component of ecosystem improvement; subsequently, active support for long-term recruitment will be needed.

Alterations to the Lewis River, most significantly timber harvest and wood transport interruption by the dams, will limit 'natural' LWD processes for the foreseeable future. Management has dramatically changed wood dynamics and these changes must be considered when planning for restoration. Past and on-going impacts will constrain the ultimate benefit of wood re-introduction projects and will require active, long-term management of LWD if wood re-introduction is to be carried out. Furthermore, managers and stakeholders must understand that rehabilitation efforts will not be able to fully restore historical wood dynamics because the underlying processes have been dramatically altered. At best, the historical structure of wood distribution in the lower river can be emulated in certain areas and to certain degrees. This structure will directly provide habitat benefits for fish and will also help to restore related processes such as pool formation, capture of fluvially transported wood, and bank erosion abatement. Because of the altered watershed processes that are necessary for natural wood dynamics, wood re-introduction will require considerable resources, buy-in from stakeholder groups, and long-term commitments from agencies and restoration organizations.

3.1.4. Monitoring, evaluation, and maintenance

All restoration projects must include a component of monitoring and evaluation, and a process for maintaining restoration efforts. Monitoring and evaluation provides critical feedback to resource managers regarding whether or not an action is working, or if it should be abandoned. The success of a restoration project is only determined through a well designed monitoring program.

Long-term maintenance will be a critical component of LWD re-introduction in the mainstem Lewis. LWD is not a static component of river systems. Even in undisturbed watersheds it is episodically removed by high flows or abandoned by migrating channels, and this attrition must be balanced by further inputs if instream LWD is to remain. In human-influenced watersheds such as the Lewis this loss is even more rapid. Thus, long-term, the physical habitat created by LWD (or any other physical manipulation) is only temporary without constant maintenance or without the restoration of the natural wood-replacing, habitat-forming processes. In the Lewis, natural wood-replacing processes may not be feasible or tolerated (e.g., large instream logs often provide a hazard to boat navigation). Nevertheless, their functions are still necessary, implying that deliberate replacement and maintenance of LWD may be a necessary component of habitat improvement. Little gain results if streams return to a degraded state due to the lack of maintaining restorative components. This is with the understanding that it may take many years for the recovery of natural processes to resume in a watershed, and in the meantime, human-induced restoration may be the only means to mitigate impaired habitat.

Using the above justification, guidance, and rationale, our objectives is to enhance the physical and biological processes of the Lewis River using wood placement. We describe the process below.

3.2. Methods

A survey of the lower river (RM 10 to 19) was conducted on August 10, 2007 in order to identify opportunities for LWD restoration projects and to determine the techniques that are necessary for wood re-introduction. Surveyors had expertise in fluvial geomorphology, fisheries biology, and hydrology, with extensive past experience with implementing LWD projects. Potential project locations were identified through visual assessment of bedform conditions, channel hydraulics, habitat quality, risk to nearby infrastructure, and access. GPS locations, photos, and notes on site conditions were taken in the field. This information was combined with reviews of aerial photos in order to refine the descriptions of project opportunities.

Recommended project techniques were specified based on past experience with implementing LWD enhancement projects. Configuration of wood placement and jam construction was specified based on site conditions as well as on the results of the historical reference conditions analysis (see Section 1.3.1). Approximate wood quantities (number of pieces and volume) were specified for each site. Board foot volumes and numbers of log truck loads were included to convey logistical considerations. The wood quantities should be viewed as approximations and may vary depending on available resources and specific project objectives.

Access conditions were described where possible based on site observations; however, further investigation will be necessary to determine access details. For the most part, landownership was not considered during project site evaluation. Any observed risks to adjacent or downstream infrastructure were described. A construction cost estimate was developed for each project opportunity. These costs are based on project unit costs from the past 25 years of LWD enhancement projects constructed by Inter-Fluve Inc and are further supplemented by unit costs obtained from RS Means Heavy Construction Cost Data (RS Means 2007). Costs are expressed in 2007 dollars. Cost ranges are a best approximation and may change depending on inflation, access conditions, material availability, or other factors.

3.3. Results and Discussion

3.3.1. Overview of Project Opportunities

A total of 15 project opportunities were identified. Nine of the project opportunities are mainstem or side-channel projects involving the construction of single or multiple LWD jams of varying sizes. Six of the projects are off-channel wood supplementation projects using small jams or individually placed pieces. The number and type of project opportunities by reach are included in Table 9. Maps of project opportunity locations are included in Appendix B.

Table 9. Location of project opportunities by reach.

Reach	Mainstem or Side-channel projects	Off-channel projects	Recovery Plan Reach Tier[1]
Lewis 4A			2
Lewis 4B	5		1
Lewis 4C			1
Lewis 5	2	3	2
Lewis 6	1		1
Lewis 7A		1	1
Lewis 7B	1	2	3

[1] Reach tiers were developed as part of the Lower Columbia Salmon and Steelhead Recovery Plan (LCFRB 2004) and reflect reach priorities for Lewis River populations as well as the relative importance of Lewis River populations to species recovery in the region. A lower tier ranking (i.e. "1") denotes greatest importance.

The majority of projects are located in the unconfined reaches (Lewis 4A – 5) below the outlet of the canyon (RM 15). The few project opportunities listed for the canyon reaches will have greater challenges with respect to channel hydraulics and access. However, these canyon reaches contain important spawning and rearing habitats that could benefit from restoration of LWD. Most of the project opportunities are located in Lewis 4B, which comprises the upstream end along Eagle Island. This reach has important habitat for multiple species and has generally favorable access and landownership.

There is relatively low risk to infrastructure associated with the identified projects. There are no bridge crossings in the project reaches. There are a few houses along the canyon reaches but there is little infrastructure close to the river. Private land, houses, and commercial properties (golf course) border the river in the lower reaches but most of the structures are located relatively high on the banks and are not within areas of likely erosion or channel avulsion. In some cases, projects may have the secondary benefit of controlling erosion along private lands. There may be avulsion risks at very high flood events but project work would likely have little to no effect on channel changes during these extreme events. Nevertheless, it will be important to properly anchor LWD installations to prevent liberated wood from causing downstream damage or boat passage interference.

In nearly all cases, projects are focused on enhancing channel margin, side-channel, or off-channel habitat and are not expected to cause barriers to boat passage through the river. In some cases, areas currently reachable by boat or bank may be reduced, but passage through the river would remain.

In most cases, wood quantity estimates included in the project descriptions are based on supplying the key pieces and structural members of log jams and do not include the numerous racked members that are found on natural jams. For this reason, total wood volumes recommended for restoration are considerably less than the historical reference volumes. In nearly all cases, LWD jam design should encourage the capture of additional wood material, which will serve to increase jam size, provide habitat benefit, and increase jam longevity. Since most wood transport has been interrupted by the Lewis River dams, it may take many years for jams to accumulate additional debris. Depending on project objectives, addition of more wood during construction may be necessary to speed up this process.

All but a few of the projects will require anchoring of wood to ensure that the installed wood remains in place. Anchoring is particularly important because wood transport has been interrupted by the hydro-system and if installed wood washes out, there is very little available to replace it. If wood is not anchored, then repeated restoration work will be necessary every few years to keep wood quantities at the desired level. If wood transport is ever provided around the hydropower system, then anchoring requirements could potentially be relaxed, assuming that if wood washes out it is more likely to be replaced; however, the sharp reduction in key piece sizes makes natural jam formation less probable (see Section 2.3). Anchoring also serves the dual purpose of keeping wood from causing potential downstream damage or boat passage interference.

3.3.2. Specific Project Opportunities

Specific LWD project opportunities are described in Appendix A.

Maps displaying the location of LWD project opportunities are included in Appendix B.

4. Fish Benefits from Proposed LWD Restoration

4.1. Lower Lewis River salmon and steelhead

This section documents the primary salmon and steelhead species present in the lower Lewis River below Merwin Dam. Included are historic and current abundance estimates, life history timing and general habitat preferences. This background information serves to inform the analysis of LWD restoration benefits in the lower Lewis River. Salmon and steelhead species in the lower Lewis River below Merwin Dam include fall and spring Chinook, coho, winter and spring steelhead, chum and bull trout.

Salmon and steelhead numbers, with the exception of fall Chinook, have declined to only a fraction of historical levels (Table 10). Extinction risks are significant for all focal species except fall Chinook – the current health (viability) ranges from very low for spring Chinook, chum, coho and summer steelhead to medium-high for fall Chinook. Returns of spring Chinook, coho, and summer and winter steelhead include both natural and hatchery produced fish (LCFRB 2004).

Table 10. Status of focal salmon and steelhead populations in the Lower North Fork Lewis River subbasin (LCFRB 2004).

Focal Species	ESA Status	Hatchery Component[1]	Historical numbers[2]	Recent Numbers[3]	Current viability[4]	Extinction risk[5]
Fall Chinook (a)	Threatened	No	18,000-20,000	3,200-18,000	Med+	20%
Spring Chinook (b)	Threatened	Yes	10,000-50,000	200-1,000	Very Low	60%
Chum (c)	Threatened	No	120,000-300,000[6]	<100	Very Low	70%
Coho (d)	Proposed	Yes	7,500-85,000	Unknown	Very Low	60%
Summer Steelhead	Threatened	Yes	20,000	Unknown	Very Low	80%
Winter Steelhead (d)	Threatened	Yes	6,000-24,000	Unknown	Low	50%

(a) focus is in lower North Fork Lewis
(b) focus is in upper North Fork Lewis
(c) Includes North Fork and East Fork Lewis populations
(d) Focus is in upper and lower North Fork Lewis
[1] *Significant numbers of hatchery fish are released in the subbasin.*
[2] *Historical population size inferred from presumed habitat conditions using Ecosystem Diagnosis and Treatment Model and NOAA back-of-envelope calculations.*
[3] *Approximate current annual range in number of naturally-produced fish returning to the subbasin.*
[4] *Propsects for long term persistence based on criteria developed by the NOAA Technical Recovery Team.*
[5] *Probability of extinction within 100 years corresponding to estimated viability.*
[6] *Historic production for the entire Lewis Basin.*

4.1.1. Population characteristics

Bull Trout

Juvenile bull trout eat terrestrial and aquatic insects, shifting to other fish (whitefish, sculpins and other trout) as they grow larger. Spawning occurs in fall after water temperatures drop below 48° Fahrenheit, in streams with cold, unpolluted water, clean gravel and cobble substrate, and gentle stream slopes. Many spawning areas are associated with cold water springs or areas where stream flow is influenced by groundwater. Bull trout egg incubation is longer than most salmon and trout species (4 to 5 months), hatching in late winter or early spring. Bull trout occur in widespread but fragmented habitats and have several life history patterns (resident, adfluvial, fluvial). Genetic sampling in 1995 and 1996 suggest that historical bull trout populations in the Lewis may have included both fluvial and resident stocks (LCFRB 2004). While vulnerable to many of the same factors that threaten other Pacific Northwest salmon populations, bull trout are more sensitive to increased water temperatures, poor water quality, and low flow conditions (Dunham and Rieman 1999). Past and continuing land management activities such as timber harvest and livestock grazing have degraded stream habitat, especially along larger river systems

and stream areas located in valley bottoms, to the point that bull trout can no longer survive or reproduce successfully.
Dunham and Rieman (1999) and Rieman and McIntyre (1995) identified maximum annual stream temperature and catchment area to be the primary factors determining bull trout distribution within a subbasin. Other potential factors include connectivity, stream gradient, geology, hydrologic regimes, presence of nonnative species, road density, and solar radiation (Dunham and Rieman 1999).

Although resident bull trout occur in the upper Lewis (Yale Lake and Swift Reservoir), significant numbers are not known to occur in the lower Lewis downstream of Merwin Dam (PacifiCorp and Cowlitz PUD 1999). It is possible that fluvial bull trout populations could be restored in the lower river. USFWS recommends that tributaries to the Lewis (Speelyai, Rain, Ole creeks) as well as the upper mainstem Lewis River should be evaluated for their potential to support bull trout local populations (USFWS 2002). However, given their habitat preference (USFWS 2002) it is unlikely that bull trout would inhabitat mainstem or side channel habitat addressed by this study.

Spring Chinook

Historically, spring Chinook were found primarily in the upper basin. Construction of Merwin Dam in 1931 blocked access to most of the spawning areas. Natural spawning in the lower Lewis now persists in the first 2 miles below Merwin Dam and in Cedar Creek (Figure 9). Spawning occurs in late August and September with juveniles rearing in the mainstem lower Lewis Basin for a full year before migrating to the Columbia in the spring (Table 11). Hatchery strays account for most of the spring Chinook spawning in the Lewis River (LCFRB 2004).

Fall Chinook

The Lewis River fall Chinook population exceeds WDFW's escapement goal in most years and was considered healthy in WDFW's 2002 stock assessment. With no hatchery fall Chinook program in the Lewis, spawning is primarily concentrated in four miles of river immediately downstream of Merwin Dam (Figure 10). Natural spawning occurs later than most other lower Columbia fall Chinook populations, extending from late October through January and peaking in mid-November. Juvenile rearing occurs near and downstream of the spawning area, most notably in the Eagle Island area (RM 10-12). Juveniles emerge in early spring and migrate to the Columbia in late spring and summer of their first year (LCFRB 2004).

Chinook habitat preferences: Generally, spring Chinook prefer to spawn in middle and upper reaches of the mainstem areas, while fall Chinook prefer the middle and lower mainstem areas (WDFW 1994). However the access restrictions posed by Merwin Dam, coupled with extensive hatchery production, has resulted in lower river spring Chinook spawning and rearing that would typically occur higher in the watershed.

Adequate spawning area and subgravel flow are important in the choice of redd sites. Preferred spawning areas of both spring and fall Chinook are often located near deep mainstem pools and in areas with abundant instream cover. Subyearling Chinook salmon in large river systems of Washington and SE Alaska (Murphy et al. 1989, Beamer et al. 2005) preferred off-channel habitat and mainstem shoreline habitats with low velocity, such as backwaters, over other mainstem habitats.

Immediately following emergence, Chinook salmon fry move downstream into the estuary or lower velocity margins of river, including side channel habitat. These low velocity areas often contain instream cover in the form of wood, root wads, overhanging vegetation or undercut banks (Healey 1991, NESC 1984). As juvenile Chinook grow, they tend to move into the deeper, higher velocity portions of the channel (Myers et al. 1998). Hayman et al (1996) showed that backwaters were preferred habitat by sub-yearling Chinook and were used in higher densities than other mainstem edge habitats.

In the Lewis River, Chinook fry use the entire range of available substrates with most age 0+ fry found within 4.6 m (15 ft) of the mainstem shore; the location of larger juveniles averages 18.6 m (61 ft) offshore (NESC 1984). Overall, velocity appears to be the most important factor affecting the distribution of fry in the river (PacifiCorp and Cowlitz PUD 2003).

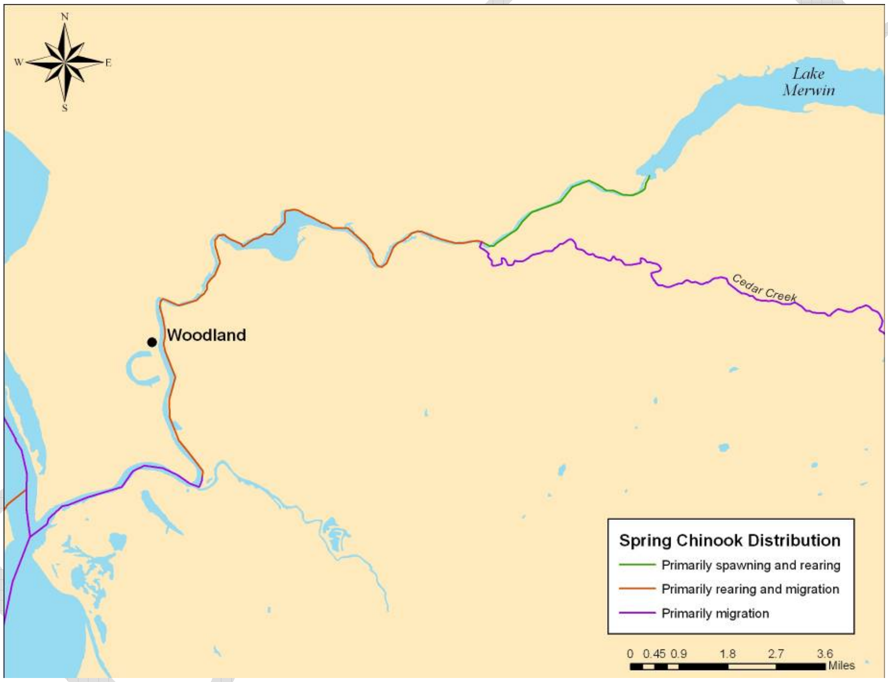


Figure 9: Spring Chinook habitat preferences in the Lower Lewis River. Source: Streamnet digital library

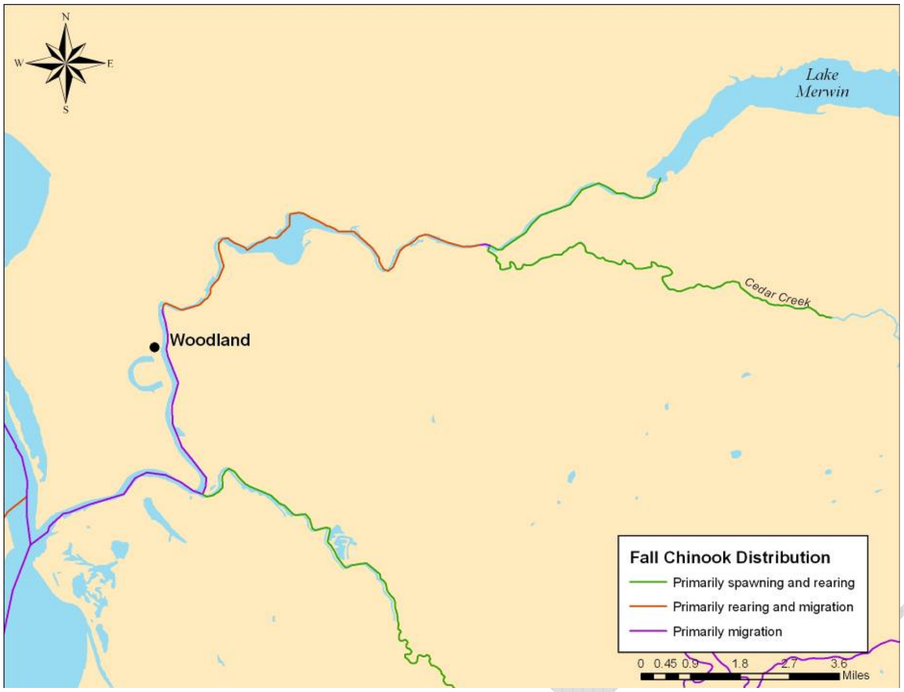


Figure 10: Fall Chinook habitat preferences in the Lower Lewis River. Source: Streamnet digital library

Coho

The historical Lewis River adult population is estimated at 7,500-85,000 fish. While Bryant (1949) described the Lewis River as one of the most important coho producers in the Columbia River basin, only "limited" historical coho spawning was thought to occur in the side channels and smaller tributaries of the mainstem Lewis River (PacifiCorp and Cowlitz PUD 2003). Although current returns are unknown, they are assumed be low and limited to the habitat downstream of Merwin Dam.

Hatchery stock accounts for most coho returning to the Lewis River with limited natural spawning (5-10 %) occurring in tributaries below Merwin Dam - Ross, Johnson, Colvin, NF and SF Chelatchie, and Cedar creeks. On low water flow years, coho spawn intensively in the Lewis River from Merwin Dam down to the Lewis River Hatchery (Figure 11). Early stock coho (Type S) spawn from late October into November and late stock (Type N) spawn from late November to March. Juveniles rear for a full year in the Lewis Basin before migrating as yearlings in the spring (LCFRB 2004).

Coho habitat preferences: Coho salmon spawn in streams along the coast and in small tributaries of larger rivers. Optimal coho salmon habitat is considered to be streams with widths of 1 to 5 m in low flow periods, gradients less than 3 percent, pool to riffle ratios of 1:1, and vegetative canopy closures of 50 to 75 percent (WDFW 1994, McMahon 1983). Spawning typically occurs in the gravelly transition areas between pool and riffle habitats in relatively stable areas of the stream channel and preferably close to cover (Reeves et al 1989, Schuett-Hames and Pleus 1996).

Following emergence, coho fry form schools and move into shallow, low velocity areas typically found in backwater pools, dam pools, and beaver ponds (Reeves et al. 1989). To reduce predation risk and increase macroinvetebrate production, young coho fry are commonly associated with cover such as overhanging or submerged logs, undercut banks, overhanging vegetation, or large substrate. As the fry mature, they begin to occupy areas near the open shoreline and progressively move into areas of higher velocity (Sandercock 1991, Reeves et al. 1989).

Preferred habitat for coho during the winter months includes side channels and backwater channels, especially those areas with heavy groundwater influence (Sandercock 1991). In the early spring, the pre-smolts move back into the mainstem channels in preparation for their seaward migration.

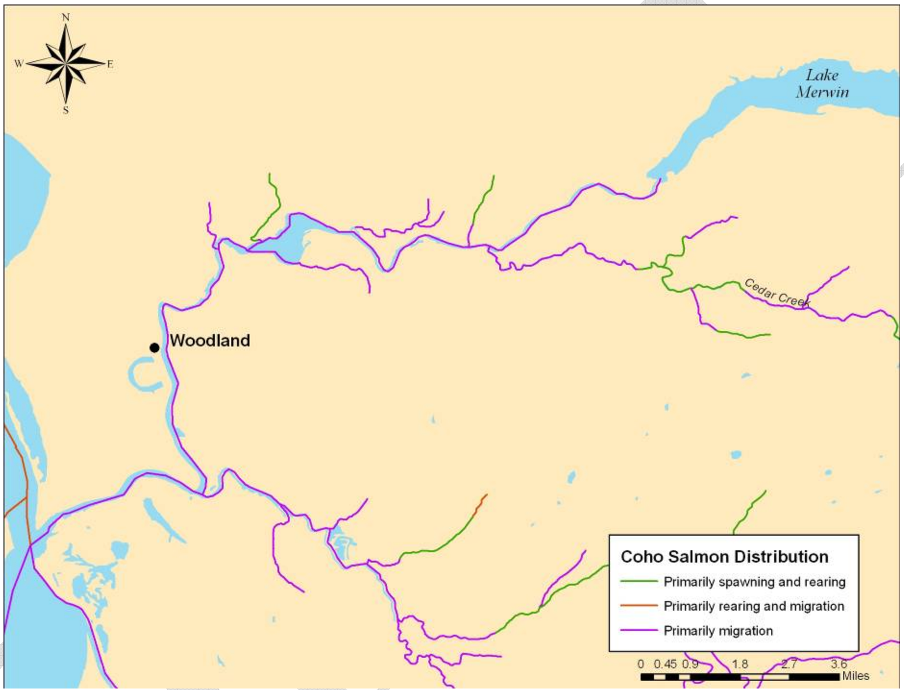


Figure 11: Coho habitat preferences in the Lower Lewis River. Source: Streamnet digital library

Steelhead

Although the historical North Fork Lewis River adult population is estimated as high as 20,000, with 80% of historic habitat inaccessible, current natural spawning returns, particularly for summer steelhead, are presumed to be very low. Within the North Fork Lewis River, the majority of steelhead are captured at the Merwin Hatchery, though an estimated 5 to 10 percent of returning steelhead do spawn naturally. Current spawning occurs in the lower Lewis and tributaries below Merwin Dam, most notably in Cedar Creek (Figure 12 and Figure 13). Unlike their winter counterparts, summer steelhead return to freshwater immature and spend several months in freshwater prior to spawning the following spring - March to early June. Both winter and summer steelhead juveniles rear for a full year or more before migrating from the Lewis Basin (LCFRB 2004).

Steelhead habitat preferences: Steelhead and rainbow trout prefer relatively small, fast flowing streams with abundant instream cover and a high proportion of riffles and pools (Barnhart 1991). The most common steelhead redd site is at the tail of a pool close to the point where the smooth surface water breaks into the riffle below.

After emergence, steelhead fry form small schools and inhabit the margins of the stream. As they grow larger, more active and territorial, they slowly begin to disperse downstream. In 1 or 2 months, steelhead fry grow to fingerling size and move into the riffle areas of the stream. Most first year steelhead live in riffles, but some larger fish also inhabit pools or deep fast runs (Barnhart 1991). Instream cover such as large rocks, logs, root wads, and aquatic vegetation are very important for juvenile steelhead. This cover provides resting areas visual isolation from competing salmonids, food, and protection from predators. Often steelhead densities are highest in streams with abundant instream cover (Bjornn and Reiser 1991).

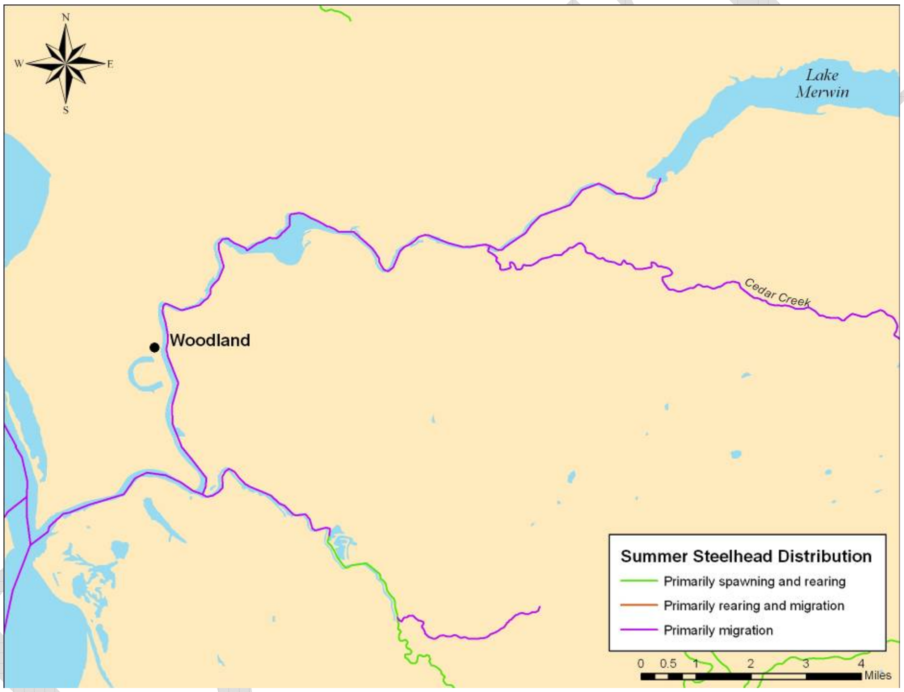


Figure 12: Summer steelhead habitat preferences in the Lower Lewis River. Source: Streamnet digital library

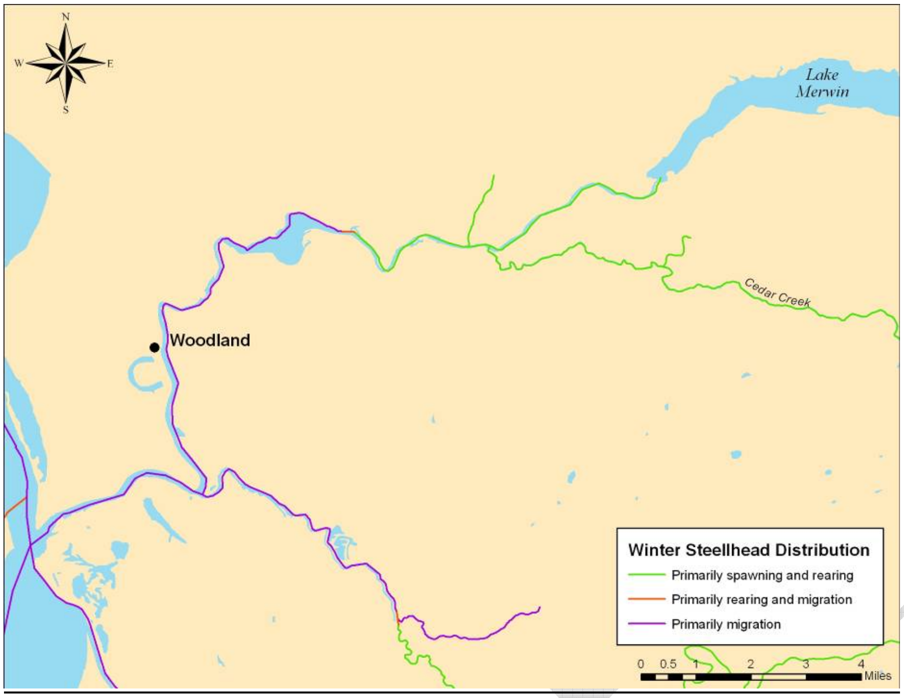


Figure 13: Winter Chinook habitat preferences in the Lower Lewis River. Source: Streamnet digital library

Chum

Historical adult populations of 120,000 – 300,000 fish were produced from the Lewis Basin in sharp contrast to the current natural spawning estimates of less than 100 fish. Natural spawning that remains occurs in the lower reaches of the mainstem, North Fork, East Fork, and in Cedar Creek (Figure 14). Adult spawning peaks in December with freshwater residence time ranging from a few hours to a few months (Johnson et al. 1997). Chum in the Lewis Basin are all naturally-produced as no hatchery chum are released in the area. Juveniles rear in the lower reaches for a short period in the early spring and are thought to migrate quickly to the Columbia (LCFRB 2004).

Chum habitat preferences: Chum salmon spawning is commonly attributed to mainstem or side-channel habitat in the lower reaches of rivers. However, in the Lewis River, chum are thought to prefer spawning habitat in side channels that contain spring water inflow or upwelling (pers. comm., E. Lesko, PacifiCorp, March 2001 as cited in PacifiCorp and Cowlitz PUD 2003).

Following their emergence, chum salmon fry form loose schools and concentrate in areas of current (facing upstream) during all times of the day. They appear to lack any type of pronounced hiding behavior (Johnson et al. 1997).

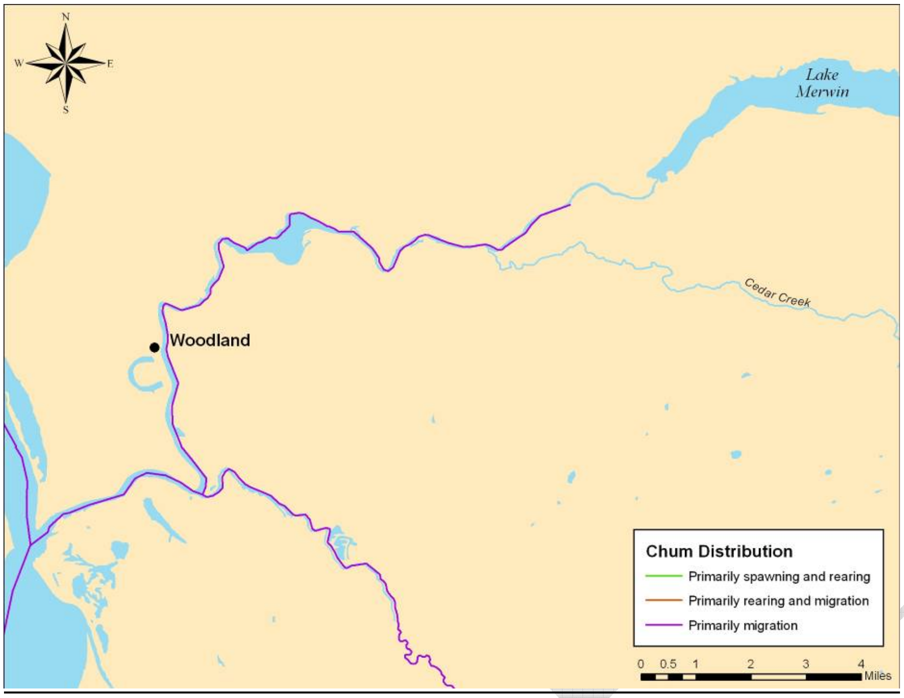


Figure 14: Chum habitat preferences in the Lower Lewis River. Source: Streamnet digital library

Table 11: Periodicity chart for salmon and steelhead species in the Lewis River Basin (PacifiCorp and Cowlitz PUD 2003)

SPECIES	LIFE STAGE	JAN				FEB				MAR				APR				MAY				JUN				JUL				AUG				SEP				OCT				NOV				DEC			
Spring Chinook	*Adult migrate*												🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																												
	Spawning																																		🟩	🟩	🟩	🟩	🟩	🟩									
	Fry emerge					🟩	🟩	🟩	🟩	🟩	🟩																																						
	Rearing	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Juv emigrate																🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																								
Fall Chinook	*Adult migrate*																																🟩	🟩	🟩	🟩	🟩	🟩	🟩										
	Spawning																																								🟩	🟩	🟩	🟩					
	Fry emerge							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																																		
	Rearing							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																								
	Juv emigrate																			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																					
Coho Salmon	*Adult migrate*																																			Type S	🟩	🟩	🟩	🟩	🟩	🟩	Type N	🟩	🟩				
	Spawning																																							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
	Fry emerge								🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																																	
	Rearing	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Juv emigrate															🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																										
Summer Steelhead	*Adult migrate*																						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																		
	Spawning									🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																																
	Fry emerge																							🟩	🟩	🟩	🟩	🟩	🟩	🟩																			
	Rearing	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Juv emigrate																🟩	🟩	🟩	🟩	🟩	🟩																											
Winter Steelhead	*Adult migrate*	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																																						
	Spawning											🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																									
	Fry emerge																									🟩	🟩	🟩	🟩	🟩	🟩																		
	Rearing	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Juv emigrate																🟩	🟩	🟩	🟩	🟩	🟩																											
Chum Salmon	*Adult migrate*																																					🟩	🟩	🟩	🟩	🟩							
	Spawning																																										🟩	🟩	🟩	🟩	🟩		
	Fry emerge								🟩	🟩	🟩	🟩	🟩	🟩	🟩																																		
	Rearing								🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																												
	Juv emigrate																	🟩	🟩	🟩	🟩	🟩	🟩																										

4.2. Benefits of LWD in the lower Lewis River

Salmon populations are responsive to changes in the riparian and freshwater environment (e.g. McMahon and Hartman 1989, Cederholm et al. 1997a, Roni and Quinn 2001a,b). In order to calculate the extent of fish benefits from LWD enhancement in the lower Lewis River, we employed the following analytical framework:

- Identify physical and biological benefits from proposed LWD restoration
- Identify species and limiting lifestages that would benefit from LWD restoration
- Quantify or qualify the magnitude of potential improvements to fish

4.2.1. Physical and biological benefits of LWD

Large woody debris influences fluvial geomorphology by altering flow and sediment movement (Abbe et al 2003). For smaller systems wood is a primary pool forming agent (Lisle and Kelsey 1982, Bisson et al. 1987), dissipating stream velocity and storing gravel, fine sediment and organic matter (Naiman and Sedell 1979, Cederholm et al. 1989). Pool volume has been found to be directly related to the amount of woody debris in a stream (Carlson et al. 1990). For larger systems, wood can have local effects on channel bed texture (Buffington and Montgomery 1999) and reach-scale effects on channel form. The highly braided channel pattern of some large alluvial rivers has been attributed to an abundance of snags and logjams (Harwood and Brown 1993, Abbe and Montgomery 2003). Logjams have also been documented as the principal mechanism forming habitat complexity (including scour pools) within mainstem and secondary side channels (Triska 1984, Sedell and Froggatt 1984, Abbe 2000, Abbe et al 2003, Collins and Montgomery 2002).

Even seemingly "transient" woody debris that does not meet the criteria of "LWD" (>10 cm diameter, >2 meters length) can have an additive functional effect on habitat quality, particularly when trapped by snags or log jams (Treadwell 1999, Gregory et al. 1991). By trapping fine particulate organic matter, accumulations of woody debris can support rich supplies of stream invertebrates (Triska and Cromack 1980, Benke et al. 1984; Bisson et al. 1987). Culp et al (1996) and Beers (1990) report that fine wood debris can increase carrying capacity for trout try and potentially adult population density as well. Bryant (1983) hypothesized that small woody debris could provide cover for fish and increase habitat complexity in a manner similar to that of large debris.

The habitat forming processes linked to LWD have been widely documented to influence fish-assemblage and juvenile abundance. LWD density and volume have been positively associated with spawning and rearing habitat, nutrient and organic matter retention and refuge during high flow events (Tschaplinski and Hartman 1983, McMahon and Hartman 1989, Fausch and Northcote 1992, Cederholm et al. 1997a; Roni and Quinn 2001a, 2001b). Pess et al. (2005) showed that backwater pools and pool habitat with logjams had greater summer species richness and significantly greater year round fish densities than those without logjams. McMahon and Reeves (1989) cited LWD as a "keystone" habitat feature for salmonids because of its pervasive influence on channel morphology, sediment and organic matter retention, water velocities, and cover.

Habitat enhancement from LWD can also indirectly affect fish populations by altering the production of aquatic macroinvertebrates. Known to be an important food supply for juvenile salmon and trout in most streams (Bilby et al. 1996), aquatic invertebrates are highly sensitive to habitat alteration and disturbance (Karr and Chu 1999). Hawkins et al. (1983) studied 13 coastal streams, and concluded that riffle habitats were the primary food producing areas for salmonids. Furthermore he found that salmonid density was correlated to invertebrate species commonly found in riffles, but not to invertebrates typically found in pool habitat. Gortz (1998) detected an increase in some macroinvertebrate species in response to instream structures and Wallace et al. (1995) observed changes in functional feeding groups only within habitats altered by wood placement. However, the scientific consensus regarding macroinvertebrate response to stream enhancement has been inconsistent. Hilderbrand et al. (1997), Laasonen et al. (1998), Larson et al. (2001), and Brooks et al. (2002) detected no difference of macroinvertebrate density or diversity in enhanced and unenhanced stream reaches. These conflicting results suggest additional information is needed. LWD's potential to affect aquatic invertebrates is indirect via riffle abundance, light and nutrient levels (Cramer 2001). Given the diversity and habitat-specific preferences of invertebrate taxa, it is reasonable to presume they would exhibit variable responses to habitat manipulations in variant systems.

Fish Benefits by Lifestage

Variable effects on salmonid abundance are reported from wood-placement projects, which in part correspond to freshwater life-history requirements for salmonids.

Winter rearing. For juvenile salmonid winter rearing, the geomorphic and physical functions provided by wood are important for survival. Juvenile coho, steelhead, and cutthroat seek deep pools formed by wood for cover and refuge from high winter flows as their metabolic activity slows with decreases in water temperature (Bustard and Narver 1975). Grette (1985) and Murphy et al. (1986) also found that densities of rearing coho juveniles were correlated with wood quantity during winter rearing, and Quinn and Peterson (1996) positively correlated LWD volume to winter survival.

Not surprisingly, the placement of wood structures for winter-rearing habitat enhancement has also shown favorable salmonid response. Wood enhancement increased winter-rearing coho abundance in two Oregon coastal streams (Solazzi et al. 2000), increased resident trout in northern Colorado streams (Riley and Fausch 1995), and increased overwinter survival in a stream on Queen Charlotte Island, British Columbia (Tripp and Poulin 1986). Nickelson et al. (1992) found increased winter densities of juvenile coho in wood-constructed pools in several Oregon coastal streams. Roni and Quinn (2001a) also reported increased coho, age-1+ cutthroat and steelhead densities (3.2 times and 1.7 times the control reach, respectively), in winter-rearing habitats with wood treatments. Cover created by bundles of brush was found to increase winter coho densities when placed in dammed pools of coastal Oregon (Nickelson et al. 1992) as well as in coastal Washington (Peters et al. 1992). Supplementation of wood to form pools and cover in off-channel habitats increased juvenile coho winter survival by over 500% (Cederholm et al. 1988). Salmonid response to wood is clearly positive for winter rearing.

Summer rearing. Because pools provide slow-water sites for summer-rearing habitat, and because wood forms pools (Montgomery et al. 1995), LWD should also be an important component of summer-rearing habitat. Yet measured salmonid responses to wood placement projects intended to increase summer-rearing habitat are mixed. Channel-spanning wood structures in Tobe Creek, Oregon resulted in a 300% increase in summer juvenile coho (House and Boehne 1986). Nickelson et al. (1992) found increased summer densities of juvenile coho in constructed pools in several Oregon coastal streams. Roni and Quinn (2001a) reported a 1.8-fold increase in summer-rearing coho densities in wood-enhanced treatment reaches compared to untreated control reaches, but they saw no difference in cutthroat or steelhead densities. However, Murphy et al. (1986) found no correlation between summer coho densities and LWD in SE Alaska streams. Similarly, Cederholm et al. (1997a) found no significant differences in the coho populations during spring and fall with two treatment types of wood and a reference site. This absence of a relationship with coho was also acknowledged in the Keogh River, British Columbia by Slaney in Cederholm et al. (1997b). Riley and Fausch (1995) also found no change in summer trout populations between their control and treatment areas. Overall, salmonid response to wood structures in summer-rearing areas is generally not as positive as it is for winter-rearing areas.

Spawning. In high-energy channels, LWD functions to retain spawning gravel and can provide physical cover for spawning adult salmonids (Schuett-Hames et al. 1994), although the conditions for success are probably dependent on a range of factors beyond the influence of any given LWD project. Salmon were found to use gravels retained by channel-spanning logs placed in the Nestucca River, Oregon (House et al. 1991), and in the North Fork Porter Creek, Washington (Cederholm et al. 1997a). However, in a study in four managed streams in British Columbia, log structures failed to change spawning gravel composition (with respect to the median grain size) even though gravel accumulations occurred following high flows (Poulin 1991).

The success of instream wood placement to augment spawning habitat likely depends on stream geomorphology and the type of structure. If the intent of the structure is to store gravels, the structure must be 1) large enough to resist mobilization, and 2) located in a stream that has the power for fluvial transport to move gravels, and 3) gravel of the sizes favorable to the targeted species must be in adequate supply upstream.

Fish Benefits by Location

Mainstem - The primary effect of LWD restoration in the mainstem lower Lewis River will be a conversion from glide to pool habitat. In the unconfined reaches (3-5), proposed LWD enhancement could increase mainstem pool habitat up to 11% with an additional 16% if enhancement were to occur throughout the North Channel of Eagle Island. In contrast, proposed LWD enhancement in the confined reaches (6 and 7) could potentially increase mainstem pool habitat 2.3%. The conversion from glide to pool habitat is particularly significant in the unconfined reaches given the current absence of pools (Table 12).

Table 12: Summary of aquatic habitat in the Lewis River between Merwin Dam and Eagle Island (PacifiCorp and Cowlitz PUD 2003)

	Riffle	Glide	Pool	Side Channel
Average length confined reach (ft)	871 (22%)	2,267 (56%)	854 (22%)	None
Average length unconfined reach (ft)	922 (17%)	3,090 (60%)	None	1,175 (23%)

The increase in pool habitat would benefit adult holding for spring Chinook, steelhead and chum. It will also benefit juvenile rearing by providing reduced velocities during high flow events and by providing cover from predation for Chinook, steelhead and coho. Although additional pool tailout habitat will be created, this is not likely to alter capacity as high quality spawning gravels are abundant and well distributed throughout the basin (R2 Resource Consultants 2004).

Side channel - The primary effect of LWD restoration in side channel habitats of the lower Lewis River will be an enhancement of existing pool habitat complexity. Chinook, coho and steelhead are likely to benefit from improved quality of side channel habitat.

Identifying the physical changes from LWD additions is the first step in this analysis. When considering habitat enhancement projects with an objective of increasing fish populations, it is essential to target conditions that limit the productivity of the population. Otherwise, costly restoration efforts could result in little to no appreciable improvement to overall population levels.

4.2.2. Potential fish productivity effects from proposed LWD restoration

Benefits from LWD restoration will be most prominent for species and lifestages that limit productivity in the reaches of the lower Lewis River. Limiting lifestages were identified for fall Chinook, chum, coho and winter steelhead by the Ecosystem Diagnosis and Treatment (EDT) model (LCFRB 2004). The habitat factor analysis within the EDT model is designed to identify the most important habitat factors affecting fish in each reach based on a comparison of historical and current conditions. A summary of the most critical life stages and the habitat factors affecting them are presented in Table 13. According to the EDT rating system, LWD affects channel stability, flow, habitat diversity, harassment and key habitat (Mobrand Biometrics, 2003). For additional information and details of the Lewis River EDT analysis, see Appendix E of the LCFRB report (2004).

Table 13: Summary of the primary limiting factors affecting life stages of focal salmonid species. Results are summarized from EDT Analysis (LCFRB 2004).

Species and Lifestage		*Primary factors*	*Secondary factors*	*Tertiary factors*
Lower Lewis Fall Chinook				
most critical	Egg incubation	sediment	channel stability, flow, harassment	
second	Spawning	flow	habitat diversity, harassment	sediment, temperature

third	Fry colonization	habitat diversity, predation	channel stability, flow, food	
Lower Lewis Chum				
most critical	Prespawning holding	habitat diversity, harassment	key habitat, temperature	
second	Spawning	flow, habitat diversity, harassment	temperature	
third	Egg incubation	flow	channel stability, harassment, temperature	
Lower Lewis Coho				
most critical	Egg incubation	sediment	channel stability	pathogens
second	0-age winter rearing	habitat diversity	flow, key habitat	channel stability, food
third	0-age summer rearing	competition (hatchery), temperature, habitat diversity	channel stability, competition (other sp), flow, food, pathogens, predation	
Lower Lewis Winter Steelhead				
most critical	Egg incubation	sediment, temperature	channel stability	
second	0-age summer rearing	habitat diversity	competition (hatchery), predation, pathogens, temperature	flow, key habitat
third	0,1-age winter rearing	habitat diversity	channel stability, flow, predation, sediment, key habitat	
	1-age summer rearing	habitat diversity	competition (hatchery)	flow, pathogens, predation, temperature, key habitat

While the EDT summary table highlights key limiting conditions, it also includes reach and tributary habitat outside the proposed study area of this report. In an effort to focus on habitat directly influenced by the proposed LWD restoration, we extracted reach specific results from the habitat factor analysis with a focus on LWD-related "primary factors". The results identify the limiting lifestage(s) for each species of interest, the principal habitat supporting that lifestage and the likelihood that LWD restoration would result in a benefit within the study area (Table 14).

Table 14: Benefit potential from proposed LWD restoration on limiting lifestages

Species	Limiting lifestage affected by LWD[1]	Principal habitat for limiting lifestage	Benefit potential in the study area[2]
Fall Chinook	fry colonization	Mainstem margins, Side channels	Moderate
Spring Chinook[3]	Spawning age-0 winter rearing age-0 summer rearing	Mainstem margins, Side channels	Low/moderate
Coho	age-0 winter rearing, age-0 summer rearing	Side channels	High

Chum	prespawning holding spawning	Mainstem margins North channel RM 11.9	Moderate
Winter steelhead	age-0,1 summer rearing age 0,1 winter rearing	Side channels, Mainstem margins (winter)	High
Summer steelhead[3]	prespawn holding	Side channels	Moderate

[1] Limiting lifestages included only if primary factors were LWD related (habitat diversity and key habitat)

[2] Benefit potential is based on reach-specific restoration and preservation potential (EDT tornado diagrams –updated in 2007)

[3] Not rated by EDT. Results based on habitat preferences, life-history timing, and historical distribution

Fall Chinook - Even though the EDT analysis documents fry colonization and age-0 summer rearing as limiting, the benefit potential for fall Chinook was moderate because the population is healthy and persistent. While LWD restoration will certainly improve fall Chinook habitat, fry colonization is a third level limiting lifestage, and thus increasing capacity would likely produce moderate improvement in population levels.

Spring Chinook - Despite the addition of LWD in the mainstem and side channels, spawning habitat for spring Chinook that was historically abundant upstream of Merwin Dam could not be restored under projected conditions. However, a low to moderate benefit potential was assigned because LWD additions would likely increase suitable age-0 rearing habitat in deep pools.

Coho – Rated with a high benefit potential, LWD additions to side channels would improve age-0 rearing conditions that limit current coho capacity.

Chum – Chum are rated with a moderate benefit potential from LWD restoration. In the mainstem, chum prefer the unconfined habitat in the lower portion of the study area (e.g. Eagle Island area). Although chum population levels have been severely depressed in recent times, they were common in the lower reaches of the Lewis River prior to the construction of Merwin Dam. Improvements to holding and spawning habitat hold the greatest potential benefit.

Winter steelhead – Winter steelhead have a high benefit potential from LWD restoration, especially projects that improve rearing habitat in side channels and mainstem margins (winter).

Summer steelhead - The high priority areas for summer steelhead restoration consist of the unconfined lower Lewis and Cedar River. LWD additions to side channels will have a moderate effect on improving rearing conditions that limit steelhead capacity.

Productivity Estimates

In an effort to quantify the potential benefits from LWD restoration, we reviewed literature for both general trends and specific monitoring results. Beamer and Henderson (1998) and Roni and Quinn (2001a) reported fish response related to LWD.

Table 15 Expected change in fish abundance attributed to LWD.

	Sub-yearling Chinook	Sub-yearling Chum	Summer trout Age 0+	Summer Older trout	Summer Coho Parr	Winter trout Age 0+	Winter Older trout	Winter Coho Presmolt
Beamer and Henderson (1998)[1]	4.25	-0.4	-3.65	0.55	8.4	1.35	1.35	3.2
Roni and Quinn (2001a)[2]	--	--	1.21	1.19	1.81	1.25	1.73	3.23

[1] Contrast in abundance from cobble to LWD sites (average value from debris piles and rootwads)

[2] Change in abundance from reference to LWD treatment sites

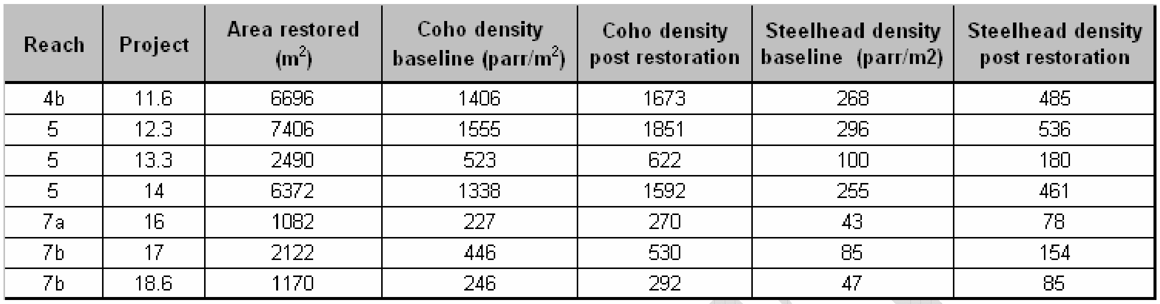
Beamer and Henderson's work (1998) was conducted on a large river system – the Skagit, whereas Roni and Quinn (2001a) evaluated smaller streams that are likely more applicable to side channel habitats on the mainstem Lewis.

Data for large river dynamics and species response to restoration is both limited and highly speculative (Triska, 1984, Beamer et al. 2005). Most evaluations of fish response to restoration have occurred in relatively small streams (< 12 m bankfull width) (Roni et al. 2004). According to Beechie et al (1994), one of the primary limitations in estimating the impact of habitat losses on salmon populations is our lack of knowledge of juvenile salmon habitat use in large rivers. This same lack of knowledge inhibits our ability to predict how habitat restoration actions in large rivers might contribute to recovery of salmon populations (Beechie et al 2002). That is not to say studies do not exist. Keeley et al. (1996) reported a 2.2-fold increase in stream-rearing anadromous salmonids and a 1.9-fold increase in resident salmonids due to increases in mainstem habitat complexity. Beamer and Henderson (1998) document a 4.25-fold increase for subyearling Chinook, but a slight decrease in abundance for sub-yearling chum. Hayman et al. (1996) reported Chinook spawning densities with and without LWD for the Skagit and Stilliguamish – both large river systems. However the results were conflicting (LWD sites more and less productive than non LWD sites), further highlighting the challenge in quantifying fish benefits from LWD enhancement in mainstem habitats of large rivers.

In sharp contrast, steelhead, and particularly coho, have an abundance of literature documenting coho response to LWD enhancement (e.g. Nickelson et al. 1992, Cederholm et al. 1997a, Roni and Quinn 2001a,b). This disparity stems from the fact that side channel habitat and smaller streams are more tractable to study. Average density estimates for coho and steelhead vary between studies and lifestages. Roni (2001a) calculated juvenile coho salmon densities that were1.8 and 3.2 times higher in treated reaches compared to reference reaches during summer and winter, respectively. He also determined that densities of age 1+ steelhead did not differ between treatment and reference reaches during summer but were 1.7 times higher in treatment reaches during winter. Regardless of past studies, absent long-term field sampling, no literature-based estimate can reliably quantify the abundance of Lewis River juvenile rearing. However, based on past studies, we can reasonably estimate the relative change in density and translate that into potential numbers of fish affected by LWD restoration.

Roni and Quinn's study of juvenile salmonid response to LWD on thirty streams in western Oregon and Washington (Roni and Quinn 2001a) represents a moderate cross section of conditions. According to their findings, LWD accounted for a 19% increase in summer coho parr density and an 81% increase in summer steelhead parr density. Assuming pre-enhancement summer parr densities of $0.21/m^2$ for coho (HLFM version 6.1 – Nickelson 1998) and $0.04\ m^2$ for steelhead (Bryant et al. 1992), we calculated the following potential benefits achieved from side channel enhancement in the lower Lewis River.

Table 16: Potential increase in coho and steelhead parr densities from LWD restoration



Reach	Project	Area restored (m^2)	Coho density baseline (parr/m^2)	Coho density post restoration	Steelhead density baseline (parr/m2)	Steelhead density post restoration
4b	11.6	6696	1406	1673	268	485
5	12.3	7406	1555	1851	296	536
5	13.3	2490	523	622	100	180
5	14	6372	1338	1592	255	461
7a	16	1082	227	270	43	78
7b	17	2122	446	530	85	154
7b	18.6	1170	246	292	47	85

4.3. Recommendations for LWD restoration

In general, the juvenile rearing lifestage, assumed to be a limiting bottleneck for several lower Lewis River fish species, would benefit from projects that restore natural habitat forming processes, increase habitat complexity, and increase habitat quality. Adult (pre-spawning) holding and spawning habitats for chum and steelhead could also benefit from LWD induced habitat change.

The proposed LWD restoration sites affect mainstem as well as side channel habitat. As discussed above, the habitats affected and potential benefits affected are notably different. Nevertheless, both mainstem summer rearing and side channel habitat have been identified as limiting (LCFRB 2004) and thus warrant restoration attention. The selection of which sites to prioritize is both a biological as well as policy decision.

We can be reasonably certain that biological benefits from increased channel complexity will positively influence fish as well as invertebrate assemblages; however, the precise increase in productivity potential, particularly in the mainstem, entails considerable uncertainty and variability. The uncertainty stems from our incomplete knowledge of large river dynamics and the variability from natural ecosystem dynamics. Therefore we recommend that equal mainstem and side channel habitats in the lower Lewis River be targeted for restoration. Specific site selection should prioritize sites that have the highest likelihood of persistence, lowest installation cost, and largest area affected. The precise number of sites to be restored is ultimately based on available resources, but from a biological perspective, it would not be unreasonable to restore all sites. Furthermore, we recommend that long-term monitoring is conducted at each of the restoration sites to identify the physical and biological response.

References

Abbe, T.B. 2000. Patterns, mechanics, and geomorphic effects of wood debris accumulations in a forest river system. Ph.D. dissertation. University of Washington, Seattle, Washington.

Abbe, T.B. and Montgomery, D.R. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research and Management 12: 210-221.

Abbe, T.B., Montgomery, D.R., Fetherston, K., and McClure, E.M. 1993. A process-based classification of woody debris in a fluvial network: preliminary analysis of the Queets River, WA. EOS, Transactions of the American Geophysical Union 73: 296.

Abbe, T.B., Pess, G., Montgomery, D.R., and Fetherston, K.L. 2003. Integrating engineered log jam technology into river rehabilitation. In Montgomery, D.R., S.M. Bolton, D.B. Booth, and L. Wall, eds. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, p. 443-482.

Abbe, T.R., and D.R. Montgomery, 2003. Patterns and processes of wood debris accumulation in the Queets river basin, Washington. Geomorphology 51: 81-107.

Agee, J.K. 1992. The historical role of fire in Pacific Northwest forests. In Walstad, J., et al. (eds.), Natural and prescribed fire in Pacific Northwest forests: pp. 25-38. Corvallis: Oregon State University Press.

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Wash. D.C.

Angermeier, P.L. and Karr, J.R. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. Transactions of the American Fisheries Society 113: 716-726.

Babakaiff, S., Hay, D., and Fromuth, C. 1997. Rehabilitating stream banks. In: Fish Habitat Rehabilitation Procedures, Slaney, P.A. and Zaldokas, D. editors. Watershed Restoration Program, Ministry of Environment, Lands and Parks, Vancouver, BC.

Barnhart, Roger A. 1991. Trout. Edited by Judith Stolz and Judith Schnell. The Wildlife Series.

Beamer, E. M., Hayman, B., Smith, D. 2005. Linking Freshwater Rearing Habitat To Skagit Chinook Salmon Recovery. Skagit Chinook Recovery Plan.

Beamer, E.M., and R.A. Henderson. 1998. Juvenile salmonid use of natural and hydromodified stream bank habitat in the mainstem Skagit River, Northwest Washington. Skagit System Cooperative. La Conner, WA. 51 p.

Beechie T., Beamer E., and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. N. Am. J. Fish. Mgmt. 14(4) 797-811.

Beechie, T.J., and Wyman, K. 1992. Stream habitat conditions, unstable slopes and status of roads in four small watersheds of the Skagit River. Skagit System Cooperative, Fisheries services for the Swinomish Tribal Community, Upper Skagit and Sauk-Suiattle Indian Tribes.

Beechie, T.J., P. Roni and E.A. Steel (eds). 2002. Ecosystem recovery planning for listed salmon: an integrated assessment approach for salmon habitat.

Beers, C.E. 1990 Effect of density, microhabitat and food on growth and survival of rainbow trout fry, Oncorhynchus mykiss (Richardson). Master's thesis. University of Calgary, Calgary, Alberta.

Benda, L. and Cundy, T.W. 1990. Predicting deposition of debris flow in mountain channels. Canadian Geotechnical Journal 27: 409-417.

Benda, L., D. Miller, J. Sias, D. Martin, R. Bilby, C. Veldhuisen, and T. Dunne. 2003. Wood recruitment processes and wood budgeting. American Fisheries Society Symposium 37:49-73.

Benke, A., T. Van Arsdall, D. Gillespie and F. Parrish. 1984. Invertebrate production in a subtropical blackwater river; the importance of habitat and life history. Ecol. Monogr. 54: 25-63.

Bilby RE, Fransen BR, and Bisson PA. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of streams: evidence from stable isotopes. Can J Fish Aquat Sci 53: 164–73.

Bilby, R.E. 1984. Removal of Woody Debris May Affect Stream Channel Stability. Journal of Forestry, 609-613.

Bilby, R.E. and Bisson, P.A. 1998. Function and distribution of large woody debris. In River Ecology and Management. Naiman R.J. and R. E. Bilby (Eds.). New York, Springer, p. 324-346.

Bilby, R.E. and Likens, G.E. 1980. Importance of debris dams in the structure and function of stream ecosystems. Ecology 61: 1107-1113.

Bilby, R.E. and Ward, J.W. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society 118: 368-378.

Bilby, R.E. and Ward, J.W. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Canadian Journal of Fisheries and Aquatic Sciences 48: 2499-2508.

Bilby, R.E., and Wasserman, L.J. 1989. Forest practices and riparian management in Washington state: Data based regulation development. In: Gresswell, R.E., Barton, B.A., and Kershner, J.L., editors. Practical Approaches to Riparian Management. U.S. Bureau of Land Management, BLM MT PT 89 001 4351, Billings, Montana.

Bisson, P.A., Bilby, R.E., Bryant, M.D., Dollof, C.A., Grette, G.B., House, R.A., Murphy, M.L., Koski, K.V., Sedell, J.R., 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In: Salo, E.O., Cundy, T.W. (Eds.), Streamside Management: Forestry and Fishery Interactions. Institute of Forest Resources, University of Washington, Seattle, pp. 143–190.

Bjornn, T.C., and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. In: Influences of forest and rangeland management on salmonid fishes and their habitats. Edited by W. R. Meehan. Special Publication 19. American Fisheries Society, Bethesda, Maryland, p. 83-138.

Braudrick, C.A., and Grant, G.E. 2000. When do logs move in rivers? Water Resource Research, 36: 571-583.

Brooks, S. S., M. A. Palmer, B. J. Cardinale, C. M. Swan, and S. Ribblett. 2002. Assessing stream ecosystem rehabilitation: Limitations of community structure data. Restoration Ecology 10(1):156-168.

Bryant, F. G. 1949. A survey of the Columbia River and its tributaries with special reference to its fishery resources. 2: Washington streams from the mouth of the Columbia River to and including the Klickitat River (Area 1). U.S. Fish and Wildlife Service. Spec. Sci. Rep. No. 62.

Bryant, M.D. 1983. The role and management of woody debris in west coast slamonid nursery streams. North American Journal of Fisheries Management 3:322-330.

Bryant, M.D.; Wright, B.E.; Davies, B.J. 1992. Application of A Hierarchical Habitat Unit Classification System: Stream Habitat and Salmonid Distribution In Ward Creek, Southeast Alaska Res. Note. PNW-RN-508. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 p..

Buffington, J.M., Montgomery, D.R., 1999. Effects of hydraulic roughness on surface textures of gravel-bed rivers. Water Resources Research 35, 3507– 3522.

Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 32:667-680.

Carlson, J. Y., C. W. Andrus, and H. A. Froehlich. 1990. Woody debris, channel features, and macroinvertebrates of streams with logged and undisturbed riparian timber in northeastern Oregon, USA. Canadian Journal of Fisheries and Aquatic Sciences 47:1103–1111.

Cederholm CJ, Houston DB, Cole DL, and Scarlett WJ. 1989. Fate of coho salmon (Oncorhynchus kisutch) carcasses in spawning streams. Can J Fish Aquat Sci 46: 1347–55.

Cederholm, C.J., Bilby, R.E., Bisson, P.A., Bumstead, T.W., Fransen, B.R., Scarlett, W.J. & Ward, J.W. 1997a. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington Stream. N. Am. J. Fish. Manage., 17: 947-963.

Cederholm, C.J., Dominguez, L.G., Bumstead, T.W. 1997b. Rehabilitating stream channels and fish habitat using large woody debris. In Fish Habitat Rehabilitation Procedures, Slaney, P.A. and Zaldokas, D. editors. Watershed Restoration Program, Ministry of Environment, Lands and Parks, Vancouver, BC.

Cederholm, C.J., Houston, D.B,. Cole, D.L., and Scarlett, W.J. 1989. Fate of coho salmon (Oncorhynchus kisutch) carcasses in spawning streams. Canadian Journal of Fisheries and Aquatic Sciences 46: 1347-1355.

Cederholm, C.J., Scarlett, W.J., and Peterson, N.P. 1988. Low-cost enhancement technique for winter habitat of juvenile coho salmon. North American Journal of Fisheries Management 8: 438-441.

Coho, C. and Burges, S.J. 1993. Dam-break floods in low order mountain channels of the PNW, Water Resources Series Tech Rep no. 138. Dept. Civil Engineering, Univ. of Washington, Seattle. 68 p.

Collins, B. D. and D. R. Montgomery. 2002. Forest development, wood jams and restoration of floodplain rivers in the Puget Lowland. Restoration Ecology 10(2): 237-247.

Collins, B.D., Montgomery, D.R. and Haas, A.D. 2002. Historical changes in the distribution and functions of large wood in Puget Lowland rivers Can. J. Fish. Aquat. Sci. 59: 66-76.

Collins, B.D., Montgomery, D.R. and Sheikh, A.J. 2003. Reconstructing the historical riverine landscape of the Puget Lowland. In Montgomery, D.R., S.M. Bolton, D.B. Booth, and L.

Wall, eds. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, p. 79-128.

Costa, J.E. 1984. Physical geometry of debris flows. In developments and Applications of Geomorphology. Edited by J.E. Costa and P.J. Fleisher, Springer-Verlag, Berlin, p. 268-317.

Cramer, S.P. 2001. The relationship of stream habitat features to potential for production of four salmonid species. Report prepared for the Oregon Building Industry Association by S.P. Cramer & Associates, Inc., Gresham, OR.

Culp JM, Podemski CL, Cash KJ, Lowell RB (1996) Utility of field-based artificial streams for assessing effluent effects on riverine ecosystems. J Aquat Ecosyst Health 5: 117–124.

Cushman, M.J. 1981. The influence of recurrent snow avalanches on vegetation patterns in the Washington Cascades. Ph.D. dissertation. University of Washington, Seattle, Washington.

Daniels, M.D., and Rhoads, B.L. 2001. Influence of a large woody debris obstruction on three-dimensional flow structure in a meander bend. Eos. Trans. AGU, 82(47), Fall Meet. Suppl., Abstract H41I-11.

Dinehart, R.L. 1997. Sediment Transport at Gaging Stations near Mount St. Helens, Washington, 1980-90, Data Collection and Analysis. USGS Professional Paper 1573.

Dunham, J.B., and B.E. Rieman. 1999. Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics. Ecological Applications 9:642-655.

Everest, F.H. and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29: 91-100.

Fausch, K. D., and T. G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Canadian Journal of Fisheries and Aquatic Sciences. 49:682-693.

Fetherston, K.L., Naiman, R.J., Bilby, R.E. 1995. Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest. Geomorphology 13: 133-144. Elsevier Science B.V.

Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. Master of Science thesis. College of Forest Resources, University of Washington. On-line version available at http://depts.washington.edu/cwws/Theses/fox.html.

Fox, M.J. 2003. Spatial organization, position, and source characteristics of large woody debris in natural systems. Ph.D. dissertation. College of Forest Resources, University of Washington. Seattle, Washington. On-line version available at http://depts.washington.edu/cwws/Theses/foxPhD.html.

Fox, M.J., and Bolton, S.M. 2007. A regional and geomorphic reference for quantities and volumes of instream wood in unmanaged forested basins of Washington State. N. Am.J.Fish. Mngmt. V.27:1. pp. 342-359.

Fox, M.J., Bolton, S., Conquest, L. 2003. Reference conditions for instream wood in western Washington. In Montgomery, D.R., S.M. Bolton, D.B. Booth, and L. Wall, eds. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, p. 361-393.

Franklin, J.F., and Dyrness, C.T. 1973. Natural vegetation of Oregon and Washington. USDA Forest Service. Gen. Tech. Rep. PNW-8.

Franklin, J.F., Spies, T.A., Van Pelt, R., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C., Bible, K., and Chen, J. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management 155: 399–423.

Gortz, P. 1998. Effects of stream restoration on the macroinvertebrate community in the River Esrom, Denmark. Aquatic Conservation: Marine and Freshwater Ecosystems 8(1):115-130.

Grant, G.E., and Swanson, F.J. 1995. Morphology and processes of valley floors in mountain streams, western Cascades, Oregon. Pages 83-101 in J.D. Costa, A.J. Miller, K.W. Potter, and P.R. Wilcock, eds. Natural and anthropogenic influences in fluvial geomorphology. Geophysical Monograph 89, American Geophysical Union, Washington DC, USA.

Gregory, S.V., F.J. Swanson, W.A. McKee and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41: 540-551.

Grette, G.B. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. MS thesis, Univ. of Wash., Seattle, WA.

Grizzel, J.D. and Wolff, N. 1998. Occurrence of windthrow in forest buffer strips and its effect on small streams in northwest Washington. Northwest Science 72: 214-223.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15: 133–302.

Harwood, K., and Brown, A.G., 1993. Fluvial processes in a forested anastomosing river: flood partitioning and changing flow patterns. Earth Surface Processes and Landforms, 18, 741-748

Hawkins, C. P., M. L. Murphy, N. H. Anderson, and M. A. Wilzbach. 1983. Density of fish and salamanders in relation to riparian canopy and physical habitat in streams of the northwestern United States. Canadian Journal of Fisheries and Aquatic Sciences 40: 1173-1185.

Hayman, R. A., E. M. Beamer, and R. E. McClure. 1996. Fiscal year 1995 Skagit River Chinook restoration research. Final project performance report (Number 1) under Northwest Indian Fisheries Commission contract #3311 for FY1995. Skagit System Cooperative. LaConner, Washington.

Healey, M.C. 1991. The Life History of Chinook Salmon (Oncorhynchus tshawytscha). In C. Groot and L. Margolis (eds.), Pacific Salmon Life Histories, p. 311-393. Univ. B.C. Press, Vancouver, B.C.

Hilderbrand, R. H., A. D. Lemly, C. A. Dolloff, and K. L. Harpster. 1997. Effects of large woody debris placement on stream channels and benthic macroinvertebrates. Canadian Journal of Fisheries and Aquatic Sciences 54:931–939.

House, R. A., V. Crispin, and J. M. Sutter. 1991. Habitat and channel changes after rehabilitation of two coastal streams in Oregon. Pages 150–159 in J. Colt and R. J. White, editors. Fisheries Bioengineering Symposium. American Fisheries Society, Symposium 10, Bethesda, Maryland.

House, R.A., and Boehne, P.L. 1986. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. North American Journal of Fisheries Management 6: 283-295.

Ikeya, H. 1981. A method for designation forested areas in danger of debris flows. In Erosion and Sediment Transport in Pacific Rim Steeplands. Edited by T.R. H. Davies and A.J. Pearce. International Assoc. of Hydrological Sciences, Publication 132: 576-588.

Johnson, O.W. et al. 1997. Status Review of Chum Salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-32. National Marine Fisheries Service. Seattle, WA. December 1997.

Karr, J.R. and E.W. Chu. 1999. Restoring Life in Running Waters - Better Biological Monitoring. Island Press, Covelo, CA

Kauffman, J.B., Beschta, R.L., Otting, N., and Lytjen, D. 1997. An ecological perspective of riparian and stream restoration in the western United States. Fisheries (Bethesda), 22: 12-24.

Keeley, E. R., P. A. Slaney, and D. Zaldokas. 1996. Estimates of production benefits for salmonid fishes from stream restoration initiatives. Watershed Restoration Management Report No. 4. Watershed Restoration Program. Ministry of Environment, Lands and Parks and Ministry of Forests, British Columbia.

Keller, E.A., and Swanson, F J. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4: 361-380.

Laasonen, P., T. Muotka, and I. Kivijarvi. 1998. Recovery of macroinvertebrate communities from stream habitat restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 8:101–113.

Larson, M.G., D.B. Booth, and S.A. Morley. 2001. Effectiveness of large woody debris in stream rehabilitation projects in urban basins. Ecological Engineering 18:211- 226.

Latterell, J.J., and Naiman, R.J. 2007. Sources and dynamics of large logs in a temperate floodplain river. Ecological Applications. Vol 17, issue 4. pp 1127-1141.

Lienkaemper, G.W., and F.J. Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Canadian Journal of Forest Research 17: 150-156.

Lisle, T.E., and Kelsey, H.M. 1982. Effects of large roughness elements on the thalweg course and pool spacing. In American Geomorphological Field Group Field Trip Guide book. Edited by Leopold, L.B. 1982 Conference, Pinedale, Wyoming. Am. Geophys. Union, Berkeley, California. pp. 134-135.

Lower Columbia Fish Recovery Board (LCFRB). 2004. Lower Columbia Salmon and Steelhead Recovery and Subbasin Plan. Prepared for Northwest Power and Conservation Council.

Malanson, G.P. and Kupfer, J.A.. 1993. Simulated fate of leaf litter and large woody debris at a riparian cutbank. Canadian Journal of Forest Research 23: 582-590.

Martin, D.J., and Benda, L.E. 2001. Patterns of instream wood recruitment and transport at the watershed scale. Transactions of the American Fisheries Society 130: 940-958.

Martinson, Finneran, and Topinka, 1984, USGS Open-File Report 84-614, and Martinson, Hammond, Mast, and Mango, 1986, USGS Open-File Report 85-631

Massong, T.M., and Montgomery, D.R. 2000. Influence of sediment supply, lithology, and wood debris on the distribution of bedrock and alluvial channels. GSA Bulletin 112: 591-599.

May, C.L., and Gresswell, R.E. 2001. Processes and Rates of Sediment and Wood accumulation in headwater streams of the Oregon Coast Range, USA. Eos. Trans. AGU, 82(47), Fall Meet. Suppl., Abstract H41I-09.

McDade, M.H., Swanson, F.J., McKee, W.A., Franklin, J.F., and Van Sickle, J. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. Can. J. For. Res. 20: 326-330.

McMahon, T. E., and G. F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Sciences 46: 1551-1557.

McMahon, T., and G. Reeves. 1989. Large woody debris and fish. Paper presented at the COPE workshop “Silvicultural management of riparian areas for multiple resources” held at Salishan Lodge, Gleneden Beach, Oregon on 12-13 December 1989. U. S. Forest Service Pacific Northwest Research Station, Portland and Oregon State University College of Forestry, Corvallis.

McMahon, T.E., 1983. Habitat Suitability Index Models: Coho salmon. U.S. Department of Interior, Fish and Wildlife Service. FWS/OBS-82/10.49.

Mobrand Biometrics, Inc. 2003. Guidelines for Rating Selected Level 2 Environmental Attributes – Ecosystem Diagnosis and Treatment. Draft

Montgomery, D.R., Buffington, J.M. 1997. Channel-reach morphology in mountain drainage basins. Geol. Soc. Am. Bull. 109: 596-611.

Montgomery, D.R., Buffington, J.M., Smith, R.D., Schmidt, K.M., and Pess, G. 1995. Pool spacing in forest channels. Water Resources Research 31: 1097-1105.

Murphy, M.L., and K.V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management 9:427-436.

Murphy, M.L., Heifitz, J., Johnson, S.W., Koski, K.V., and Thedingda, J.F. 1986. Effects of clearcut logging with and without buffer strips on juvenile salmonids in Alaskan streams. Canadian Journal of Fisheries and Aquatic Science 43: 1521-1533.

Murphy, M.L., J. Heifetz, J.F. Thedinga, S.W. Johnson, and K.V. Koski. 1989. Habitat Utilization by Juvenile Pacific Salmon in the Glacial Taku River, Southeast Alaska. Can. J. Fish. Aquat. Sci. 46:1677-1685.

Murphy, M.L., Thedinga, J.F., Koski, K.V., and Grette, G.B. 1984. A stream ecosystem in an old-growth forest in southeast Alaska, Part V. Seasonal changes in habitat utilization by juvenile salmonids, Pages 89-98 in W. R. Meehan, T. R. Merrell, and T. A. Hanley, eds. Fish and wildlife relationships in old-growth forests: proceedings of a symposium held in Juneau, Alaska, 12-15 April 1982.

Myers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grand, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. Status review of Chinook Salmon from Washington, Idaho, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-35, 443 p.

Naiman, R.J. and J.R. Sedell. 1979. Characterization of particulate organic matter transported by some Cascade Mountain streams. J. Fish. Res. Bd. Canada 36:17-31.

Naiman, R.J., Fetherston, K.L., McKay, S., and Chen, J. 1998. Riparian forests. Pages 289-323, in Naiman, R.J., and Bilby, R.E. (Editors). River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer-Verlag, New York.

Nakamura, F. and Swanson, F.J. 1994. Distribution of coarse woody debris in a mountain stream, western Cascade range, Oregon. Canadian Journal of Forest Research 24: 2395-2403.

NESC (Northwest Energy Services Company). 1984. Verification of Habitat Utilization Criteria for Juvenile Fall Chinook Salmon in the North Fork of the Lewis River, Washington. Final Report prepared for Pacific Power and Light Company.

Nichols, R.A. and Sprague, S.G. 2003. The Use of Long-line Cabled Logs for stream bank rehabilitation. In Montgomery, D.R., S.M. Bolton, D.B. Booth, and L. Wall, eds. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, p. 422-442.

Nickelson, T. E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon coastal streams. Oregon Department of Fish and Wildlife Information Reports Number 98-4, Portland, Oregon.

Nickelson, T.E., Solazzi, M.F., Johnson, S.L., and Rodgers, J.D. 1992. Effectiveness of selected stream improvement techniques to created suitable summer and winter rearing habitat for juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49: 790-794.

O'Connor, J.E., M.A. Jones, and T. L. Haluska. 2003. Flood plain and channel dynamics of the Quinault and Queets Rivers, Washington, USA. Geomorphology 51 (2003) 31–59.

Oregon Department of Forestry: 1995, A guide to placing large wood in streams, Salem, OR, Forest Practices Section, 13 p.

PacifiCorp and Cowlitz PUD. 1999. Study Plan Document for the Lewis River Hydroelectric Projects. Draft. Portland, OR, and Longview, WA. October 29, 1999, as amended.

PacifiCorp and Cowlitz PUD. 2003. Licensee’s 2001 Technical Study Status Reports for the Lewis River Hydroelectric Projects.

Pess, G., Montgomery, D.M., Beechie, T.J., and Holsinger, L. 2003. Anthropogenic alteration to the biogeography of Puget Sound salmon. In Montgomery, D.R., S.M. Bolton, D.B. Booth, and L. Wall, eds. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, p. 129-154.

Pess, G., Morley, S., Hall, J.L. & Timm, R.K. 2005. Monitoring floodplain restoration. In P. Roni, ed. Monitoring stream and watershed restoration, pp. 127-166. Bethesda, MD, American Fisheries Society. 350 pp.

Peters, R.J., Knudsen, E.E., Cederholm, C.J., Scarlett, W.J., and Pauley, G.B. 1992. Preliminary results of woody debris use by summer-rearing juvenile coho salmon in the Clearwater River, Washington. In Proceedings of the coho workshop, Nanaimo, B.C. May 1992. Berg, L. and Delaney, P.W. editors. Pages 323-339.

Pleus, A.E. and D. Schuett-Hames. 1998. TFW Monitoring Program Methods Manual for the reference point survey. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-98-002. DNR #104.

Poulin, V.A. and Assoc. 1991. Stream rehabilitation using LOD placements and off-channel pool development. BC Ministry of Forests. Vancouver, BC

Prestegaard, K. and Folk, K. 2001. Floodplain Flow Resistance Greatly Enhanced by Woody Debris Jams created in Riparian Vegetation Eos. Trans. AGU, 82(47), Fall Meet. Suppl., Abstract H41I-12.

Quinn, T.P. and Peterson, N.P. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (Oncorhynchus kisutch) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53: 1555-1564.

R2 Resource Consultants. 2004. Kalama, Washougal and Lewis River Habitat Assessments Chapter 3: The North Fork Lewis River Basin.

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. U.S. Forest Service Technical Report PNW-245

Reeves, G.H., Hall, J.D., Roelofs, T.D., Hickman, T.L., and Baker, C.O. 1991. Rehabilitating and modifying stream habitats. In Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19: 519-557.

Rieman, B.E., and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124:285-296.

Riley, S.C. and Fausch, K.D. 1995. Trout population response to habitat enhancement in six northern Colorado streams. Can J. Fish. Aquat. Sci. 52: 34-53.

Roberts, W.J. 1920. Report on White-Stuck and Puyallup Rivers in King and Pierce Counties, Washington. Chief Engineer, Inter-County River Improvement.

Robison, G.E., and Beschta, R.L. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. Forest Science. 36: 790-801.

Roni, P. and T.P. Quinn. 2001a. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:282-292.

Roni, P. and T.P. Quinn. 2001b. Effects of artificial wood placement on movements of trout and juvenile coho in natural and artificial channels. Transactions of American Fisheries Society 130:675-685.

Roni, P., A. Fayram, and M. Miller. 2004. Monitoring and evaluating instream habitat enhancement. in P. Roni, editor. Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, Maryland.

Rot, B.W., Naiman R.J., and Bilby, R.E. 2000. Stream channel configuration, landform, and riparian forest structure in the Cascade Mountains, Washington. Can. J. Fish. Aquatic Sci.: 57: 699-707.

Sandercock, F. K. 1991. Life History of Coho Salmon (Oncorhynchus kisutch). In C. Groot and L. Margolis (editors), Pacific salmon life histories, p. 396-445. Univ. British Columbia Press, Vancouver.

Schuett-Hames, D., A. Pleus. 1996. Literature Review and Monitoring Recommendations for Salmonid Spawning Habitat Availability. Timber, Fish, and Wildlife Report AM-9-96-002, Northwest Indian Fisheries Commission, Olympia, WA.

Schuett-Hames, D., Pleus, A., Bullchild, L., and Hall, S. 1994. Timber-Fish-Wildlife Ambient Monitoring Program Manual. Northwest Indian Fisheries Commission, Olympia, Washington.

Schuett-Hames, D., Pleus, A.E., Ward, J., Fox, M., and Light, J. 1999. TFW Monitoring Program Methods Manual for the large woody debris survey. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-004. DNR #106. March.

Sedell, J.R. and J.L. Froggatt. 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. Verb. Int. Ver. Limnol. 22: 1828-1834.

Sedell, J.R. and W.S. Duval. 1985. Water Transportation and Storage of Logs. Chapter 5 in: Influence of forest and rangeland management on anadromous fish habitat in Western North America, W.R. Meehan, Technical Editor. USDA Forest Service General Technical Report PNW-186

Sedell, J.R., and Luchessa, K.J. 1981. Using the historical record as an aid to salmonid habitat enhancement. Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. October 23-28, Portland, OR.

Solazzi, M.F., Nickelson, T.E., Johnson, S.L., and Rodgers, J.D. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Can. J. Fish. Aquat. Sci. 57: 906-914.

Spence, B.C., Lomnicky, G.A., Hughes, R.M., and Novitzki, R.P. 1996. An Ecosystem Approach to Salmon Conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.

Spies, T.A., and Franklin, J.F. 1991. The structure of natural young, mature, and old-growth Douglas fir forests in Oregon and Washington. In Wildlife and Vegetation of Unmanaged Douglas fir Forests. Technical coordinators: L.F. Ruggiero, K.B. Aubrey, A.B. Carey, and M.H. Huff. USDA For. Serv. Gen Tech. Rep. PNW-GTR-285, p. 91-109.

Tilling, R.I., L. Topinka, and D.A. Swanson. 1990. The Eruptions of Mount St. Helens: Past, Present, and Future. USGS General Interest Publication.

Treadwell S (ed.) 1999. Managing snags and large woody debris. Pp. 15-22 in: Riparian land management guidelines, Volume two: On-ground management tools and techniques. (Eds. Lovett S, Price P). Land and Water Resources Research and Development Corporation, Canberra.

Tripp, D.B., and Poulin, V.A. and 1986. The effects of logging and mass wasting on salmonid spawning habitat in streams on the Queen Charlotte Islands. Research Branch, Ministry of Forests and Lands, Victoria.

Triska, F.J. and K. Cromack. 1980. The role of wood debris in forests and stream. Pages 171-190 in R. H. Waring, editor. Forests: fresh perspectives from ecosystem analysis. Oregon State University, Corvalis.

Triska, F.J., 1984. Role of wood debris in modifying channel geomorphology and riparian areas of a large lowland river under pristine conditions: a historical case study. . Verh. Internat.Verein. Limnol., 22,1876-1892

Tschaplinski, P. J., and G. F. Hartman. 1983. Winter distribution of juvenile coho salmon (Oncorhynchus kisutch) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Canadian Journal of Fisheries and Aquatic Sciences 40: 452-461.

U.S. Fish and Wildlife Service. 2002. Chapter 20, Lower Columbia Recovery Unit, Washington. 89 p. In: U.S. Fish and Wildlife Service. Bull Trout (Salvelinus confluentus) Draft Recovery Plan. Portland, Oregon.

Wallace, J.B., Webster, J.R., and Meyer, J.L. 1995. Influence of log additions on physical and biotic characteristics of a mountain stream. Canadian Journal of Fisheries and Aquatic Sciences 52: 2120-2137.

Wallerstein, N.P., Throne, C.R., and Doyle, M.W. 1997. Spatial distribution and impact of large woody debris in northern Mississippi. In Wang, S.S.Y., Langendoen, E.J., and Shields, F.D., eds., Proceedings of the Conference on the Management of Landscapes Disturbed by Channel Incision, Center for Computational Hydroscience and Engineering, The University of Mississippi, p. 145-150.

Washington Forest Practices Board. 1997. Board Manual: Standard Methodology for Conducting Watershed Analysis. Under Chapter 222-22 WAC. Version 4.0. Olympia, Washington

WDFW (Washington Department of Fish and Wildlife). 1994. Species Plans for the Integrated Landscape Management Plan Lewis-Kalama River Watershed Pilot Project. WDFW. September 1994.

Wei, X., Kimmins, J.P. 1998. Asymbiotic nitrogen fixation in harvested and wildfire-killed lodgepole pine forests in the central interior of British Columbia. For. Ecol. Management; 109: 343–353.

Willingham, W. 1983. Army Engineers and the Development of Oregon: A History of the Portland District U.S. Army Corps of Engineers. Chapter 4: Project Management and River Improvements, 1880-1920.

Appendix A

Descriptions of LWD Project Opportunities

Main channel and primary side-channel sites

There are several good locations for re-introducing LWD into the mainstem Lewis or into major side channels (active during low flows). These projects primarily consist of the construction of medium to large log jams anchored into the bed or banks of the river. Most of the projects consist of meander bend jams located at the margin of the low flow channel and extending into the channel to provide both summer and winter rearing habitat benefit.

RM 18.2

Location: In canyon, RM 18.2

Reach: Lewis 7B
Recovery Plan Reach Priority: Tier 3

Description: Potential project on right bank at the eddy below a mainstem riffle. Bedrock outcrop offers protection from flood flows and maintains the eddy along the right bank. There is potential for a large jam at the eddy against the bedrock. A deep pool at this location provides good rearing cover; construction of a large jam would enhance cover for juveniles rearing in the pool and accessing the adjacent riffle for feeding. Shade is provided from bedrock wall and overhanging trees. Combine with off-channel enhancement at backwater area immediately upstream to enhance winter rearing. Add wood to off-channel for cover and complexity.

Project area along right bank at bedrock outcrop

Upstream off-channel area on right bank

Techniques and Specifications: A medium-sized channel margin jam could be constructed at this site, extending approximately 200 feet along the bank, beginning at the bedrock outcrop and extending upstream. The jam would include key pieces anchored along the channel wall and bed. Interlocking pieces would be placed among key members, tying into the key members where necessary to counteract buoyant forces. Smaller large wood pieces can be interlaced within and packed into matrix of jam.

There are signs of strong turbulence at high flood flows at this location. To ensure jam stability, key members must be anchored to bedrock wall and streambed and/or ballasted with rock and boulders.

Wood quantities
Volume (m^3): 75 - 100
Number of pieces (range 1-4m^3 ea): 35 - 50
Board feet: 15,000 to 20,000
Log truck loads: 3 - 4

The backwatered off-channel area immediately upstream could benefit from installation of wood for cover and complexity. Focus wood supplementation in 150 foot section extending from outlet of back channel on right bank to furthest extent of wetted area. Remaining portions of side-channel/overflow channel complex (just upstream) already contain wood and are not connected with main channel at lower flows. These areas are a lower priority for enchancement. Wood added to backwater channel can be ballasted with vertical pilings and/or boulder ballast.

Wood quantities
Volume (m^3): 50
Number of pieces (range 1-4m^3 ea): 25
Board feet: 10,000
Log truck loads: 2

Species/life stage benefit: Steelhead, Chinook, coho, chum adult holding. Chinook, Steelhead, and coho juvenile rearing year-round. Winter rearing for coho and steelhead at side channel. Good adjacent feeding at riffle.

Access: Poor access. May be access to side channel area from property above the canyon rim. Potential access from residence across river at low water. Access at this site needs to be investigated further in coordination with landowners.

Risks: No immediate downstream infrastructure at risk. Hatchery intake facility is 2 miles downstream. Would not impede boat access through reach.

Construction cost estimate: $50,000 to $70,000 for log jam, not including design, permitting, or monitoring. $30,000 for off-channel enhancement portion. 20% increase placed on costs due to difficulty in access. Specific access conditions may change costs considerably, or could potentially make project infeasible altogether.

RM 15.5

Location: Just downstream from Cedar Creek on right bank, RM 15.5

Reach: Lewis 6
Recovery Plan Reach Priority: Tier 1

Description: There is a large eddy on the right bank created by a large cobble bar downstream. The bar has aggraded from local widening of the river in this area. Historical aerial photo series show that the dominant bar has shifted from left bank to right bank since 1938. Bar layering observed on site indicate gravels and cobbles in matrix of fines. The bar is currently being slowly eroded and is contributing gravels downstream; however, rapid transport of bar is possible during high flow event. One or two large log jams on upstream face of bar and extending throughout eddy area (200-400 lineal feet of streambank) would protect bar from rapid transport while still allowing movement of material through reach. Scour at jam could provide excellent pool habitat that would be enhanced by wood cover from constructed log jam. There is a mainstem riffle immediately adjacent to the site that would provide a feeding source for juvenile salmonids.

View of project site from upstream

Techniques and Specifications: A large jam could be constructed at this site. Key members could be anchored through burial with gravels and cobbles on upstream face of large bar. The face of the jam would extend out into the river. Vertical snags would be buried within the jam to collect fluvial wood contributed during high flows. Because much of the wood will be buried by bar sediments, key members will require a minimum of 24 inches dbh and 40 feet long to allow large wood to extend into the channel. Large logs with attached root wads are recommended. Approximately 5-10 key members could be buried into bar with other structural members interlaced within jam complex. Boulder ballast may also be necessary depending on channel hydraulics at high flows.

<u>Wood quantities</u>
Volume (m^3): 200 – 250
Number of pieces (range 1-4m^3 ea): 100 – 125
Board feet: 40,000 to 50,000
Log truck loads: 8-10

Species/life stage benefit: Steelhead, Chinook, coho, and chum adult holding. Chinook, Steelhead, and coho juvenile rearing year-round. Adjacent riffle just downstream for feeding. This is a known spawning riffle. Wood placements would enhance sorting of bed material that could benefit spawning.

Access: Good access on right bank downstream at boat ramp area. A road was observed that allows car access. Further investigation of the road would have to be determined to see if truck access is available to allow wood mobilization

Risks: No immediate downstream infrastructure at risk. Would not impede boat access through reach.

Construction cost estimate: $100,000 to $140,000 for jam(s), not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

RM 13.8

Location: Just upstream of golf course bend on right bank, RM 13.5 to 14

Reach: Lewis 5
Recovery Plan Reach Priority: Tier 2

Description: Potential for medium to large wood jams interspersed with individual wood placements along right bank for at least a half mile, potentially extending down to tall, actively eroding bank near RM 13.5. Wood placements should be designed to capture additional wood during flood flows. This is an outer bend where natural wood accumulations would be expected based on low slope and observations of shallow bar formation. Nevertheless, high energy along right bank during flood flows would provide local scour around wood for habitat. Wood structures could be designed to move thalweg off the bank during floods, which would have the secondary purpose of affording flood erosion protection to adjacent landowners who otherwise may resort to hardened measures (e.g. rip-rap, gabions, barbs) during or following large flood events.

View looking downstream at project site (right bank)

Techniques and Specifications: Wood placements will be tied into the existing right bank to provide habitat at most flows and create bank roughness to reduce the likelihood of bank erosion. Extent of effort could very tremendously depending on objectives and resources available. A series of log jams and individual pieces could extend along the bank as much as a half mile. A smaller portion of the bank could also be treated and still provide localized bank protection and habitat benefit. Key members can be buried in bank, ballasted with boulders, and in some areas, tied into existing standing trees along the shoreline.

<u>Wood quantities</u>
Volume (m^3): 75 – 300
Number of pieces (range 1-4m^3 ea): 50 – 150
Board feet: 15,000 to 60,000
Log truck loads: 3 – 12

Species/life stage benefit: Steelhead, Chinook, coho, and chum adult holding. Chinook, Steelhead, and coho juvenile rearing year-round.

Access: Great access through private property if it could be arranged.

Risks: Golf course and private residences along right bank adjacent to and downstream of project site. Project could increase bank stability, potentially decreasing erosion risk to these properties. Would not impede boat access through reach.

Construction cost estimate: $60,000 to $180,000 depending on level of effort desired, not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

RM 12.8

Location: Along downstream end of golf course on right bank, RM 12.8

Reach: Lewis 5
Recovery Plan Reach Priority: Tier 2

Description: There is the potential for 3-6 medium sized jam structures along the right bank at RM 12.7, adjacent to the golf course. There currently is some rip-rap along the bank. Wood structures could be anchored into the bank and to existing trees and would extend into channel for cover along deep pool area. This would increase habitat complexity along this uniform segment.

View of project site from mid-channel

Techniques and Specifications: This is a high energy area during high flows and proper anchoring would be critical to secure wood. In order to keep wood in place at this location, it will be necessary to utilize boulder ballast and cable unless very large key pieces can be delivered to the site. Anchoring through burial in the bank may be possible but steepness of bank may limit the use of this technique. Approximately 200-300 feet could be treated.

<u>Wood quantities</u>
Volume (m^3): 25 – 50
Number of pieces (range 1-4m^3 ea): 15 – 25
Board feet: 5,000 to 10,000
Log truck loads: 1 – 2

Species/life stage benefit: Steelhead, Chinook, coho, and chum adult holding – spawning occurs at the next riffle just upstream. Chinook, Steelhead, and coho juvenile rearing year-round.

Access: Good access through golf course if it could be arranged. Access could be obtained from the downstream boat ramp near the golf course.

Risks: Golf course along right bank adjacent to and downstream of project site. Project could increase bank stability, potentially decreasing erosion risk. Would not impede boat access through reach.

Construction cost estimate: $30,000 to $55,000, not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

RM 11.9

Location: Just upstream of Eagle Island where limited flow spills over to north channel, RM 11.8 and RM 12. And north channel Eagle Island.

Reach: Lewis 4B
Recovery Plan Reach Priority: Tier 1

Description: The primary flow has been shifting from the north to the south channel since the 1930s. Low flow may no longer reach the north channel if this trend continues. Log jam structures could be designed to maintain summer-season flow into the north channel at the two primary sites where low-water spills over from the main channel to the north channel. Structures could be designed to encourage scour (deepening) of cross-over channels to maintain low-water conveyance. Cover and habitat complexity would also be created.

Aerial view of project site cross-over channels just upstream of bifurcation at upstream end of Eagle Island. River flow is from right to left.

Techniques and Specifications: There are 2-3 crossover channels in this area, comprising a combined width of 400 – 500 feet. Jams could be placed along the margins of these channels to maintain scour depths suitable to convey adequate summer flows into the north channel. Significant effort would need to be put towards hydraulic analysis to ensure that structures function properly in maintaining flow through the channels. To ensure stability of structures, ballast would need to be provided using boulders and cables. Structures would be designed to constrict flow and increase depths at cross-over channels. Logs would also be placed on adjacent bars and islands in order to encourage flow through cross-over channels and to discourage avulsions across bars.

Wood quantities
Volume (m^3): 120 – 175
Number of pieces (range 1-4m^3 ea): 60 – 90
Board feet: 25,000 to 35,000
Log truck loads: 5 – 7

Species/life stage benefit: Maintenance of flow in the north channel would increase available habitat and habitat diversity for all species. Wood structures would provide cover and scour pools that would benefit steelhead, Chinook, coho, and chum adult holding – spawning occurs along this area. Structures would benefit Chinook, steelhead, and coho juvenile rearing year-round. The cross-over channels comprise good riffles for juvenile feeding.

Access: There is good access to right bank at river access point on right bank at head of Eagle Island. It is uncertain how difficult it would be to obtain access to project site on mid-channel bar. Could potentially ford stream at low water or access via upstream end where bar abuts right bank. Landowner permission may be required.

Risks: There are private residences on right bank adjacent to project area, but these would be at minimal risk from project. Would not impede boat access through reach. May improve boat access through north channel.

Construction cost estimate: $70,000 to $110,000, not including design, permitting, or monitoring. Design costs will be greater than in other large wood enhancement projects because of the level of effort required for hydraulics analysis. A 10% increase was added to the costs to account for potentially difficult access into mid-channel area. Costs may change if additional access issues are encountered.

North Channel Eagle Island

Location: North Channel Eagle Island.

Reach: NA
Recovery Plan Reach Priority: NA

Description: The primary flow has been shifting from the north to the south channel since the 1930s. Low flow may no longer reach the north channel if this trend continues. If flow in the north channel is maintained through log jam structures (see project 11.9) or other means, then enhancing LWD habitat in the north channel becomes very beneficial for salmon rearing and potentially spawning. Wood could be placed throughout the north channel from the upstream end down to tidewater influence.

View downstream at top end of north channel at Eagle Island

Techniques and Specifications: The north channel could hold a very large volume of wood for fish habitat in the form of log jams and individual pieces. The wood could be placed from the inlet of the bifurcation downstream to tidewater. Jams could be anchored by burying key members or could be created on the surface using boulder and cable ballast techniques depending on the number of key pieces available. This effort could be scalded depending on objectives and resources available. An upper estimate of wood quantities and costs are therefore given.

<u>Wood quantities</u>
Volume (m^3): up to 1,500
Number of pieces (range 1-4m^3 ea): up to 750
Board feet: up to 300,000
Log truck loads: up to 60

Species/life stage benefit: There is significant benefit to habitat capacity in maintaining flow in the north channel. This would increase available habitat and habitat diversity for all species. If north channel flow is maintained, wood structures would enhance cover and create scour pools that would benefit steelhead, Chinook, coho, and chum adult holding and juvenile rearing.

Access: Access could occur from the boat ramp below the bifurcation and possibly at other locations along the north bank depending on landowner cooperation.

Risks: Private residences adjacent to and downstream of project site but these would be at minimal risk from project. Projects could be designed to decrease bank erosion in some areas. Projects could be designed to not impede boat access through reach.

Construction cost estimate: Up to $600,000, not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

RM 11.6

Location: Left bank near upstream end of south Eagle Island channel, RM 11.6

Reach: Lewis 4B
Recovery Plan Reach Priority: Tier 1

Description: There is a large side channel on the left bank that is active at low summer flows. There is currently some wood in the side-channel but scour pools are scarce and riparian cover is poor. Medium to large jams and individual pieces could be placed throughout the 1,200 foot long side channel. At the head of the side channel, a large point bar jam could be constructed that wraps the upstream of the island and extends into the main channel; this would provide habitat benefit to the main channel and could be designed to ensure flow conveyance to the side channel during low flows. This is one of the best sites on the lower Lewis for wood habitat. A secondary benefit of wood placed at the head of the south channel is the increased roughness that would encourage continued flows in the north channel, thereby increasing available habitat and habitat diversity. Restoration of riparian plant communities (alder, cottonwood, and willow) should be a major component of work in this area.

View looking downstream at project area. Head of side-channel is on the right.

Techniques and Specifications: The active side channel area could be enhanced with jams and individual pieces. Wood could be anchored through burial into the banks or through boulder ballast if necessary. Flood energy is lower and ability to utilize width and capacity at large flows enables a more stable site for wood habitat creation. Wood extending into main channel at head of side channel (bar apex jam) could be anchored through burial of key members into bar and through boulder ballast.

<u>Wood quantities</u>
Volume (m^3): 200 - 220
Number of pieces (range 1-4m^3 ea): 100 - 115
Board feet: 40,000 to 45,000
Log truck loads: 8 – 9

Species/life stage benefit: Wood placements in the side channel would provide cover and scour pools that would benefit juvenile steelhead, Chinook, and coho rearing throughout the year. A point bar jam at the head of the side channel would also enhance adult holding. There is high spawning value in this area.

Access: There appears to be an old access road on the left bank adjacent to the project area. This area is owned by Clark County. The terrain is flat and wood could be skidded to the site easily. Low water access could also potentially be obtained at the river access point on right bank at head of Eagle Island.

Risks: There are private residences downstream of the project site, but these would be at minimal risk from project. Would not impede boat access through reach.

Construction cost estimate: $110,000 to $130,000, not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

RM 11.3

Location: Right bank near upstream end of south Eagle Island channel, RM 11.3

Reach: Lewis 4B
Recovery Plan Reach Priority: Tier 1

Description: There is a large eddy on the right bank just upstream of the outlet of the side channel described above for Project 11.6. This is part of an old meander scar. The eddy provides good opportunity for a large log jam that would have some protection from large flows but that would scour sufficiently to provide good habitat benefit. Wood jams and complexes could extend upstream as far as 400 feet and downstream as far as 700 feet from this large right bank eddy. Jams could also be placed on the mid-channel bar adjacent to this site.

Constructed wood jams in this area should be designed to encourage the capture of additional wood. The development of large jams is likely to re-establish a dynamic, shifting channel condition in this reach. However, the availability of wood and bed material transport (or lack thereof) through the hydro-system needs to be considered when designing for a dynamic channel condition.

View of project site looking upstream

Techniques and Specifications: A large jam could be constructed in the large right bank eddy (approximately 200 lineal feet) and could partially extend into the main channel. The larger the wood the greater opportunity to extend into the low flow active channel. There currently exists a large jam that is mostly above the bankfull channel on the southern bank of the eddy. This is likely from the February 1996 flood. Some of this wood could be incorporated into the constructed jam within the active channel.

Wood jams could also extend a few hundred feet upstream or downstream of the eddy and secured into the bank through burial, pilings, or anchored to standing trees. An abandoned side/overflow channel on the right bank that begins at the eddy location could potentially be re-activated as part of this effort. There is also the potential for construction of an in-channel bar jam in center-left channel near the left bank side-channel outlet. This could be designed to enhance bar formation in-channel, thereby increasing the potential for dynamic channel processes.

If suitably sized key pieces cannot be obtained and if it is deemed essential that wood does not mobilize during high flows, then any wood placed in-channel will have to be ballasted using boulders, cable, or burial.

The wood quantities listed below represent a relatively high level of effort for this site. This effort could be scaled to include less wood supplementation depending on objectives and available resources.

Wood quantities
Volume (m^3): 500 - 600
Number of pieces (range 1-4m^3 ea): 250 - 300
Board feet: 100,000 to 120,000
Log truck loads: 20 – 24

Species/life stage benefit: Log jam construction would provide habitat for adult holding for Chinook, coho, steelhead, and chum – There are known spawning sites adjacent to the project area. Juvenile rearing habitat would be provided throughout the year for Chinook, coho, and steelhead.

Access: Access could be provided from the south (left) bank from the same access road described for project 11.6. Any access to Eagle Island would likely provide access to this site. Portions of this area are owned by Clark County.

Risks: There are private residences downstream of the project site, but these would be at minimal risk from project. This area offers good opportunity for encouraging dynamic channel processes (i.e. lateral boundary adjustment) but the potential impact to downstream residences on the left bank would need to be further assessed. This project could be designed to not impede boat access through reach.

Construction cost estimate: $250,000 to $300,000, not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

RM 11

Location: Left bank 2/3 distance up the south Eagle Island channel, RM 11

Reach: Lewis 4B
Recovery Plan Reach Priority: Tier 1

Description: There is an outlet to a back water channel (old meander scar) on the left bank upstream from where the stream draws close to houses and the roadway. Wood jams in this area could provide cover and habitat complexity for rearing fish. Wood placements (jams and/or individual pieces) could extend upstream into the back channel and downstream along the left bank of the main channel. There are several pieces of medium-sized logs there currently and accumulations of additional wood are very likely if jams are constructed.

View of site from mid-channel

Techniques and Specifications: Small to medium sized cover habitat log jams could be constructed within the backwater channel and extending downstream along the left margin of the main channel. The jams would be best completed using rock and cable unless large key pieces can be obtained. The jams would emulate large wood that has rafted into location and accumulated over time. This site is not conducive to burial using existing substrate.

Wood quantities
Volume (m^3): 50 – 75
Number of pieces (range 1-4m^3 ea): 25 – 40
Board feet: 10,000 to 15,000
Log truck loads: 2 – 3

Species/life stage benefit: Wood cover placements (jams and individual pieces) would provide habitat for adult holding for Chinook, coho, steelhead, and chum – The site is adjacent to a spawning riffle. Juvenile rearing habitat would be provided throughout the year for Chinook, coho, and steelhead.

Access: The adequacy of access is uncertain. There is a high bank adjacent to the site with private residences. Low water access could potentially be obtained from Eagle Island.

Risks: There are private residences adjacent to and downstream of the project site, but these would be at minimal risk from the project. This project would not impede boat access through reach.

Construction cost estimate: $30,000 to $50,000, not including design, permitting, or monitoring. A 10% increase was applied to the costs because of uncertain access. Costs may change if additional access issues are encountered.

Off-channel and secondary side-channel sites

Many backwater/side channel areas could be improved through wood additions that increase cover for hiding and feeding. These projects primarily target juvenile rearing and may have benefits throughout the year depending on species. Some off-channel habitats are more suited to winter rearing only and may be mostly dewatered during summer low flows. Groundwater monitoring and temperature monitoring should be conducted to ensure that temperature, flow quantity, and dissolved oxygen conditions are adequate to support high quality rearing in these areas.

RM 18.6

Location: In canyon, RM 18.6

Reach: Lewis 7B
Recovery Plan Reach Priority: Tier 3

Description: Add wood to off-channel area on left bank – small jams and individual pieces. Shading is provided by trees on valley hillslope to south.

Techniques and Specifications: Wood can be added along 200 – 300 feet of backwater channel. Anchoring wood with pilings or burial should be sufficient. If large key pieces can be obtained (>4m^3), these can be placed partially up on the bar and extended into the channel. Other pieces can be interlaced or cabled to key members.

Wood quantities
Volume (m^3): 25 – 50
Number of pieces (range 1-4m^3 ea): 15 – 25
Board feet: 5,000 to 10,000
Log truck loads: 1 – 2

Species/life stage benefit: spring, fall, and winter juvenile rearing for Chinook, coho, and steelhead. Good access to riffle just downstream for feeding.

Access: Access unknown. May be difficult due to canyon. Potential access from boat ramp upstream on right bank.

Risks: No immediate downstream infrastructure at risk. Hatchery intake facility is over 2 miles downstream. Would not impede boat access through reach.

Construction cost estimate: $30,000 to $42,000, not including design, permitting, or monitoring. A 20% increase was applied to the costs because of potentially difficult access. Costs may change if additional access issues are encountered.

RM 17

Location: In canyon, RM 17

Reach: Lewis 7B
Recovery Plan Reach Priority: Tier 3

Description: Great off-channel holding ponds on left bank just upstream from large spawning area. Not quite connected to surface flow at low-summer flow levels. There is some wood already in ponds. Add wood to increase quantities – small jams and individual pieces. Consider making ponds accessible during low summer flow. Shading provided by trees on valley hillslope to south.

Techniques and Specifications: Wood can be added along 300 – 400 feet of backwater channel. Anchoring wood with pilings or burial should be sufficient. If large key pieces can be obtained (>4m^3), these can be placed partially up on the bar and extended into the channel. Other pieces can be interlaced or cabled to key members.

Wood quantities
Volume (m^3): 100 – 150
Number of pieces (range 1-4m^3 ea): 50 – 75
Board feet: 20,000 to 30,000
Log truck loads: 4 – 6

Species/life stage benefit: spring, fall, and winter juvenile rearing for Chinook, coho, and steelhead. Flow is not active at time of survey (Aug 10, 2007). Good access to riffle just downstream for feeding.

Access: Access unknown. May be difficult due to canyon.

Risks: No immediate downstream infrastructure at risk. Hatchery intake facility is 4,500 feet downstream. Would not impede boat access through reach.

Construction cost estimate: $70,000 to $100,000, not including design, permitting, or monitoring. A 20% increase was applied to the costs because of potentially difficult access. Costs may change if additional access issues are encountered.

RM 16

Location: Across and just upstream from hatchery, RM 16

Reach: Lewis 7A
Recovery Plan Reach Priority: Tier 1

Description: There is an off-channel area on the left bank across and just upstream from the hatchery. It is active as a side/overflow channel at high flows but is disconnected at the top end at low summer flows. Cover habitat could be enhanced by adding wood to the channel – small jams and individual pieces. Shade is provided by trees on the valley hillslope to the south.

Techniques and Specifications: Focus on upper 300 – 400 feet of off-channel/side channel. Wood could be added down the side channel and on the bar. If large key pieces could be imported, a larger jam complex could be constructed near the inlet and worked out into the channel. Anchoring wood with pilings (vertical snags) or burial should be sufficient. If large key pieces can be obtained (>4m^3), these can be placed partially up on the bar and extended into the channel. Other pieces can be interlaced or cabled to key members. Pieces that extend into the main channel at the upper end will need to be very large or ballasted with boulders or buried into the bar if they are to remain stable at high flows.

Wood quantities
Volume (m^3): 75 – 150
Number of pieces (range 1-4m^3 ea): 40 – 75
Board feet: 15,000 to 30,000
Log truck loads: 3 – 6

Species/life stage benefit: spring, fall, and winter juvenile rearing for Chinook, coho, and steelhead. Flow is barely not active at time of survey (Aug 10, 2007). Good access to riffle just downstream for feeding.

Access: Access from hatchery and cross river at low water. Potential access from left bank but would have to construct road down steep valley wall.

Risks: Hatchery and access area downstream but risk would be minimal to these areas. Would not impede boat access through reach.

Construction cost estimate: $60,000 to $95,000, not including design, permitting, or monitoring. A 20% increase was applied to the costs because of potentially difficult access. Costs may change if additional access issues are encountered.

RM 14

Location: On left bank upstream of golf course, RM 14

Reach: Lewis 5
Recovery Plan Reach Priority: Tier 2

Description: Large backwater channel on left bank (remnant channel). It is currently devoid of wood. Channel extends a total of 1,500 feet. Add small jams and individual pieces to create high and low flow cover habitat.

Techniques and Specifications: Focus on lower 300 – 400 feet of off-channel/side channel, where cover can be created in close proximity to main channel. Anchoring may require boulder ballast to ensure wood stability. If large key pieces can be obtained (>4m^3), these can be placed partially up on the bar and extended into the channel. Other pieces can be interlaced or cabled to key members.

<u>Wood quantities</u>
Volume (m^3): 50 – 75
Number of pieces (range 1-4m^3 ea): 25 – 40
Board feet: 10,000 to 15,000
Log truck loads: 2 – 3

Species/life stage benefit: Year-round juvenile rearing for Chinook, coho, and steelhead.

Access: Access through private property on south bank if it can be arranged.

Risks: There are adjacent and downstream residences but risk would be minimal to these areas. Would not impede boat access through reach.

Construction cost estimate: $35,000 to $50,000, not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

RM 13.3

Location: On left bank at south bend across from golf course, RM 13.3

Reach: Lewis 5
Recovery Plan Reach Priority: Tier 2

Description: Off-channel complex on left bank at outside of bend (remnant channel). It is currently devoid of wood. Add small jams and individual pieces to enhance cover adjacent to main channel.

Techniques and Specifications: Focus on areas closest to main channel: 300 – 400 feet total. Anchoring could use pilings (vertical snags) and partial burial in bar sediments. If large key pieces can be obtained (>4m^3), these can be placed partially up on the bar and extended into the channel. Other pieces can be interlaced or cabled to key members.

Wood quantities
Volume (m^3): 50 – 75
Number of pieces (range 1-4m^3 ea): 25 – 40
Board feet: 10,000 to 15,000
Log truck loads: 2 – 3

Species/life stage benefit: Year-round juvenile rearing for Chinook, coho, and steelhead.

Access: Access may be challenging. There is potential access through private property on south bank if it can be arranged, or from golf course across river.

Risks: The golf course is across the stream and there are downstream residences, but risk would be minimal to these areas. Would not impede boat access through reach.

Construction cost estimate: $40,000 to $55,000, not including design, permitting, or monitoring. Costs increased by 10% to account for potential access challenges. Costs may change if additional access issues are encountered.

RM 12.3

Location: On right bank downstream of golf course, RM 12.3

Reach: Lewis 5
Recovery Plan Reach Priority: Tier 1

Description: Large off-channel area on right bank. This is a remnant channel that was cut off by levee fill to protect the highway. The channel currently lacks adequate wood for cover. There is beaver activity. Fill removal and reconnection of the main channel should be considered if roadway erosion concerns can be adequately addressed. There are net pens operated by Fish First in this off-channel area that would also have to be taken into consideration. At the least, small jams and individual pieces could be added to increase cover and complexity for rearing juveniles. Temperature and water quality should be assessed during low flows to ensure conditions are suitable for rearing habitat. Flow connections could be created via pipes through levee fill in order to keep summer temperatures equivalent to the mainstem, if necessary.

Techniques and Specifications: Focus on margins of backwater area closest to main channel (first 500 feet). Due to deep water, this site is best suited for rock ballasted cover type jam habitat unless large key pieces (>4m^3) can be delivered.

Wood quantities
Volume (m^3): 50 – 75
Number of pieces (range 1-4m^3 ea): 25 – 40
Board feet: 10,000 to 15,000
Log truck loads: 2 – 3

Species/life stage benefit: Year-round juvenile rearing for Chinook, coho, and steelhead.

Access: Potential access from adjacent roadway and levee extending from upstream boat launch area. Further investigation would be required to determine if heavy equipment could access this site.

Risks: The Fish First net pens would have to be worked around or relocated. Boat access into the backwater area may be impacted but boat access in the main channel would not be affected.

Construction cost estimate: $35,000 to $50,000, not including design, permitting, or monitoring. Costs are based on favorable access and may change if access issues are encountered.

Appendix B

LWD Project Opportunity Maps

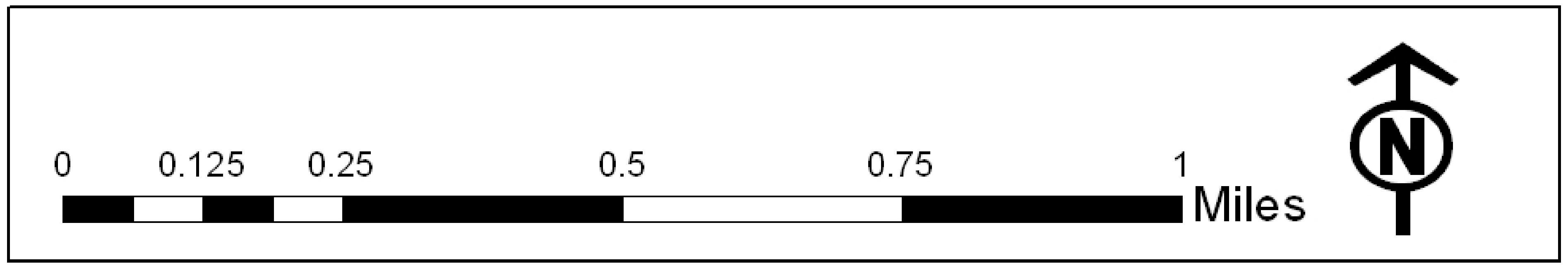
Lewis River LWD Project Opportunities

River Mile 10 to 13

Legend

🟨 Mainstem or Primary Side-channel Project

🟩 Off-channel Project



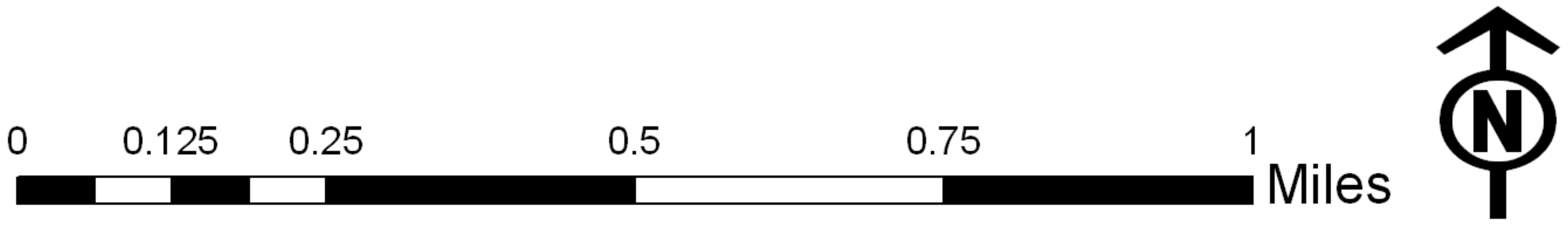
inter·fluve inc.

Lewis River LWD Project Opportunities

River Mile 13 to 16

Legend

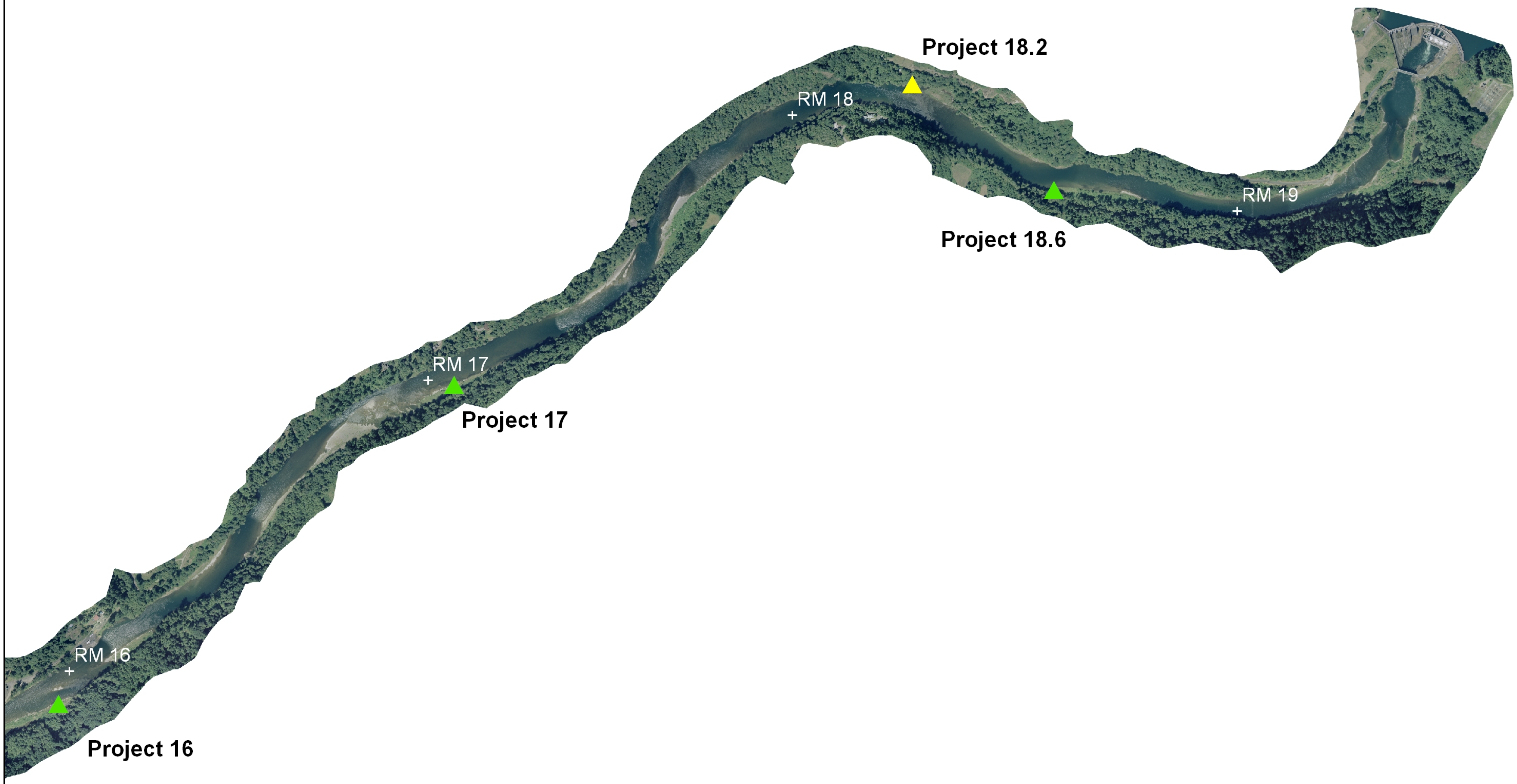
▲	Mainstem or Primary Side-channel Project
▲	Off-channel Project



inter·fluve Inc.

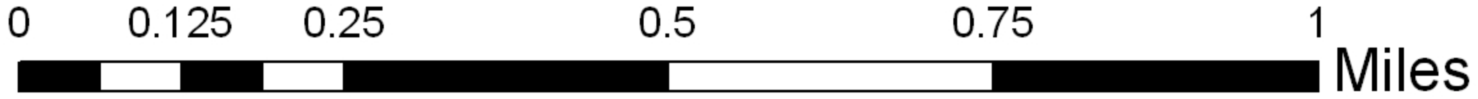
Lewis River LWD Project Opportunities

River Mile 16 to 19



Legend

▲	Mainstem or Primary Side-channel Project
▲	Off-channel Project



inter·fluve inc.